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VOLUME XIX

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PHOSPHATE AND SILICATE IN THE SOUTHERN OCEAN

By

A. J. CLOWES, M.Sc., A.R.C.S.

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PHOSPHATE AND SILICATE IN THE SOUTHERN OCEAN

By A. J. Clowes, M.Sc., A.R.C.S.

(Plates I–XXV; Text-figs. 1–29)

INTRODUCTION

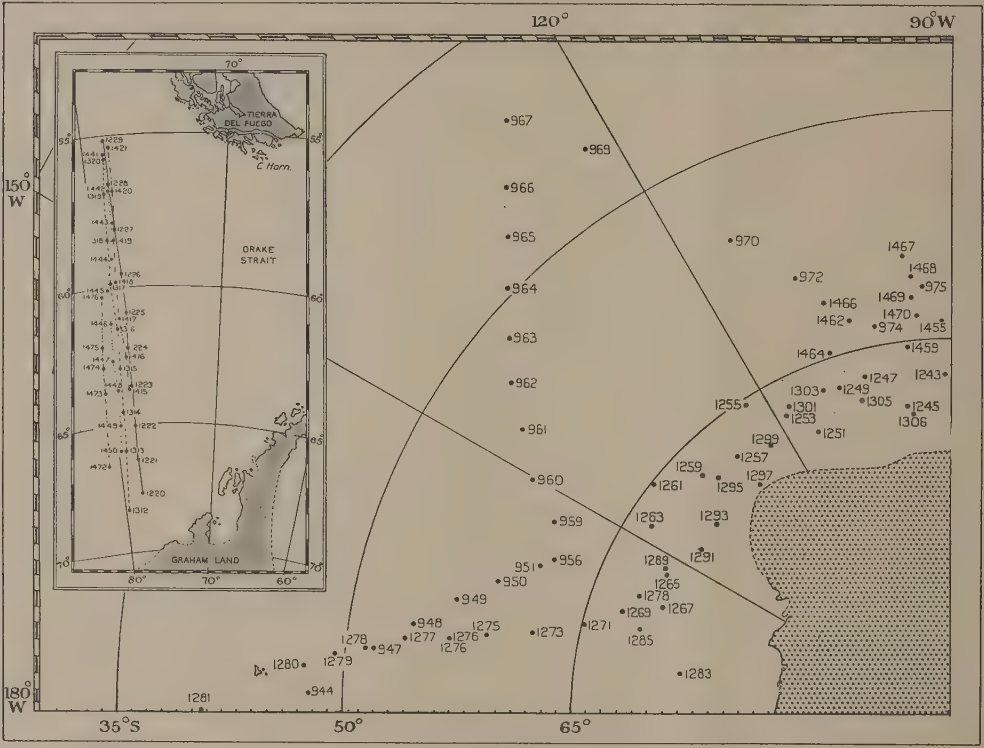
For some years past the Discovery Committee has been collecting hydrological data in southern waters. Amongst these data is a large number of estimations of the phosphate and silicate contents of the various waters encountered in the Southern Ocean. The importance of a knowledge of the distribution and fluctuations of phosphate and silicate in this ocean may clearly be seen when it is realized that these nutrient salts are essential to the life economy of the huge concentrations of plankton found in southern waters. The plankton forms the basic food supply of the whales, and in the production of this food supply enormous quantities of these two nutrient salts are withdrawn from the sea water. This report describes our present knowledge of the distribution, fluctuations and cycles of these two important salts.

Consideration has only been given to those estimations which were obtained by analysis as soon as the samples of sea water had come to laboratory temperature; only the results of analyses carried out on board R.R.S. 'Discovery II' are included here. It is felt that by excluding all material which had to wait more than about 12 hours before analysis, a more accurate series of results is obtained, since changes in the nutrient salt content of the samples due to phytoplankton and bacteria is minimized.

So far only part of the data has been published (*Discovery Reports*, IV, pp. 1–232), but reference to the plates at the end of this report will show that most of the data have been inserted in the vertical sections which have been so carefully drawn by Miss E. C. Humphreys. The data not shown in the vertical sections are usually those between 0 and 200 m.; these have been omitted only to prevent confusion in the plates which, however, were constructed with the aid of all the data. At most stations observations were made at 0, 10, 20, 30, 40, 50, 60, 80, 100, 150, 200, 300, 400, 600, 800, 1000, 1500, 2000, 2500, 3000 m. and at intervals of 500 m. to the bottom. Unprotected thermometers were used with the reversing bottles so that the true depth of the sample could be calculated.

No attempt has been made to correct the data for salt error. It was considered that the present state of our knowledge on this question was insufficient to warrant the making of such corrections which indeed might have to be recalculated later on. All values of phosphate and silicate contents are given as milligrammes of P_2O_5 and SiO_2 respectively per cubic metre of sea water. The coeruleomolybdic method of Denigès as adapted by Atkins (1923*a*), was used for the analysis of phosphate, whilst the method of Diénert and Wandenbulcke, introduced into sea-water analysis by Atkins (1923*b*), was used for silicate analysis. The silicate results are given according to the standards of King and Lucas (1928).

I should like to express my indebtedness to my colleagues, Mr H. F. P. Herdman and Dr G. E. R. Deacon, who have assisted me in collecting all the samples and, together with Mr Saunders, have helped to make the estimations on which this report is founded. In the actual writing of the report I have been very fortunate in having access to a proof-copy of Dr Deacon's "Hydrology of the Southern Ocean", *Discovery Reports*, xv, pp. 1–124, which has been of great help. Dr T. J. Hart and I have discussed many of the problems which have arisen, and I am indebted to him for many suggestions and for all my facts about phytoplankton. Finally, but by no means least, the samples could only have been obtained by the full co-operation and skill of the ship's officers and by the loyal and painstaking service of the seamen, often in the worst of weathers.


120°
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150° W
180° W
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50°
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TIERRA DEL FUEGO
C. Horn
DRAKE STRAIT
GRAHAM LAND
70°
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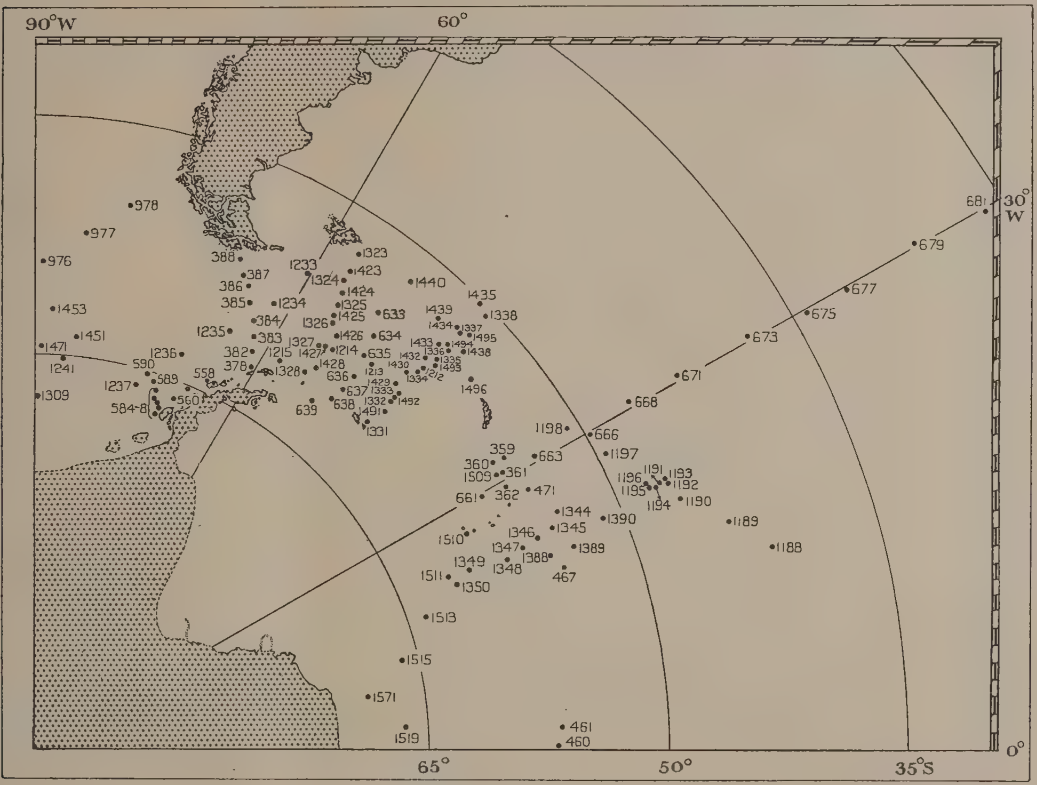
Fig. 1. Positions of stations where observations for phosphate or silicate were made in the South Pacific sector of the Southern Ocean.

Figs. 1–5 show the position of the majority of the stations at which observations were made. In some of the routine lines of repeated observations and in particular in the Scotia Sea and in 80° W, all the stations are not shown.

Before proceeding to the main portion of this report a preliminary and very brief account of the chief water layers of the Southern Ocean and their movements will be given. For a more complete account the reader is advised to consult Deacon (*loc. cit.*). Also, since we are principally dealing with the Antarctic zone, some remarks on the close connexion between nutrient salts and plankton in this important zone will be made in this introduction.

All round the Antarctic Continent, Antarctic surface water spreads northwards in a shallow layer until it reaches a position which has been termed the Antarctic convergence; here it sinks below the surface layer of sub-Antarctic water. In the area of mixing, 100–200 miles north of the convergence, the Antarctic surface water becomes mixed with warmer water from the subsurface and surface waters of the sub-Antarctic zone and eventually forms part of the Antarctic intermediate current. The layer immediately below the Antarctic surface water is the warm deep water, whose movement has a southerly component. This layer lies at a great depth north of the Antarctic convergence and flows almost horizontally until it approaches the Antarctic zone. It then climbs steeply over a third layer of water, the Antarctic bottom water which itself sinks towards the north, and south of the Antarctic convergence continues its flow towards the south at a much lesser depth.


90°W
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30° W
0°
65°
50°
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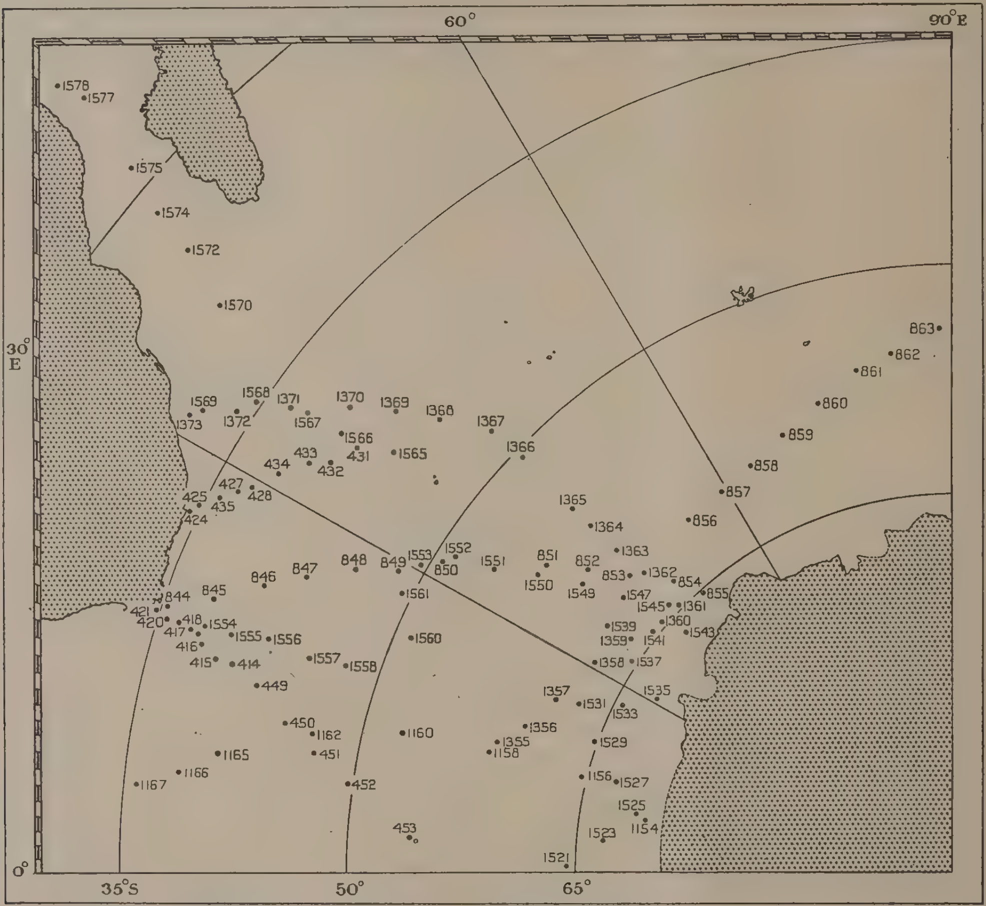
Fig. 2. Positions of stations where observations for phosphate or silicate were made in the South Atlantic sector of the Southern Ocean.

North of the Antarctic convergence and south of the subtropical convergence the upper part of the water column consists of sub-Antarctic water, a much thicker layer than the Antarctic surface water and including a subsurface current and the Antarctic intermediate current. Below this there is the warm deep water which in turn overlies the Antarctic bottom water which flows to the north.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0°
35°S
50°
65°
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1371
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Fig. 3. Positions of stations where observations for phosphate or silicate were made in the sector of the Southern Ocean south of South Africa.

In general the north and south circulation of the various waters of the Southern Ocean are very similar to the South Atlantic circulation which is shown in Fig. 6.[1]

Amongst the nutrient salts utilized in the life-economy of the plankton, more particularly by the phytoplankton, are those of phosphate and silicate. Of the form in which these salts exist in the ocean very little is known, and at present we shall deal only with the amount of nutrient salt available for the metabolism of the plankton.

It seemed to me that a very close relationship must exist between the phytoplankton of the Southern Ocean and the amount of phosphate and silicate present, and that any

[1] This figure is taken from Deacon (1937), *Discovery Reports*, xv, p. 4.

discussion of the content of these salts in the sea must necessarily involve some conceptions of the distribution of phytoplankton and a brief résumé of the waxing and waning of the enormous concentrations found in spring and summer in the Antarctic. Dr T. J. Hart informs me that within the Antarctic zone it is possible to distinguish three areas characterized by the type of phytoplankton communities they support, and, broadly speaking, by their geographical relation to the Antarctic convergence and to the ice-edge. This distinction is necessarily less clearly defined where geographical features lead to any marked difference from the average latitude of the convergence, as for instance in the eastern South Pacific Ocean. The three areas are: a northern region extending some 300 miles south of the Antarctic convergence, a southern region extending some 200 miles north of the ice-edge, and a rather less definite intermediate zone within which our observations are not yet sufficiently numerous to permit any average extent being determined. These limits are to some extent arbitrary, as the latitude of the Antarctic

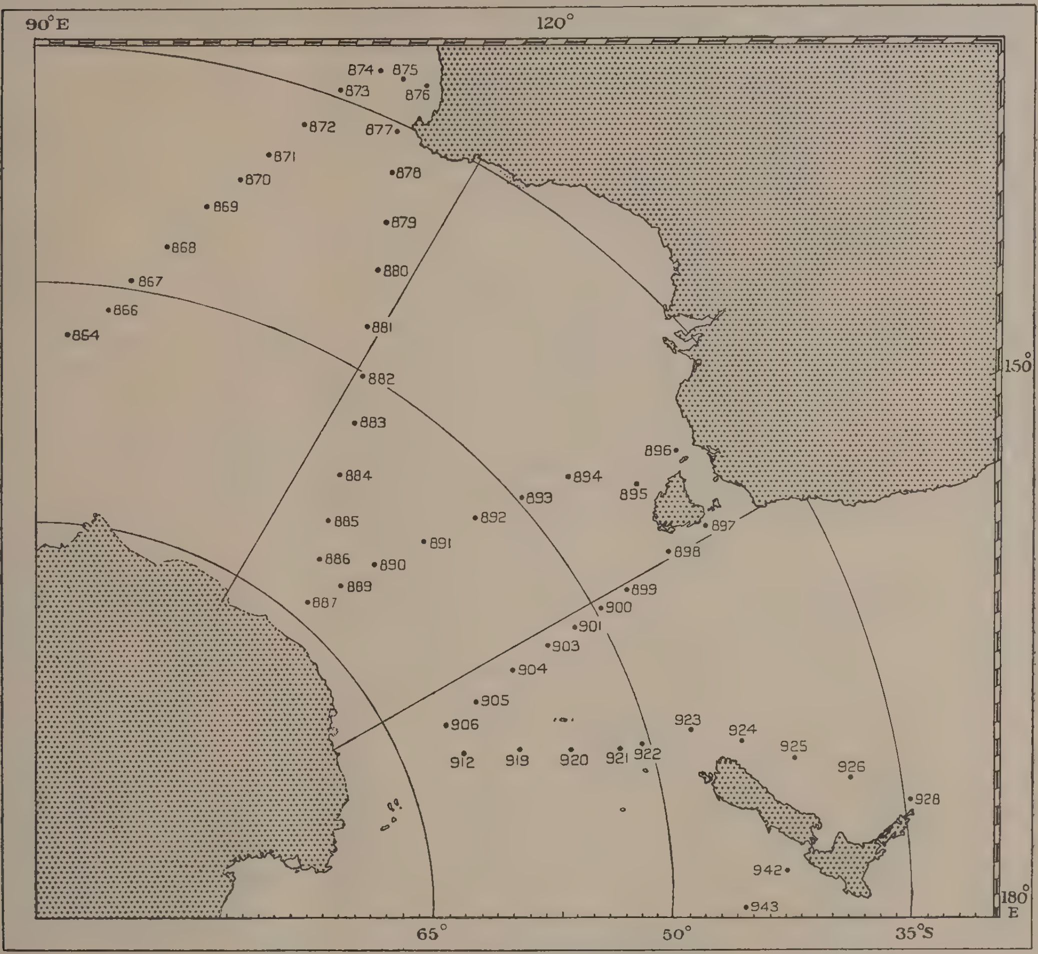
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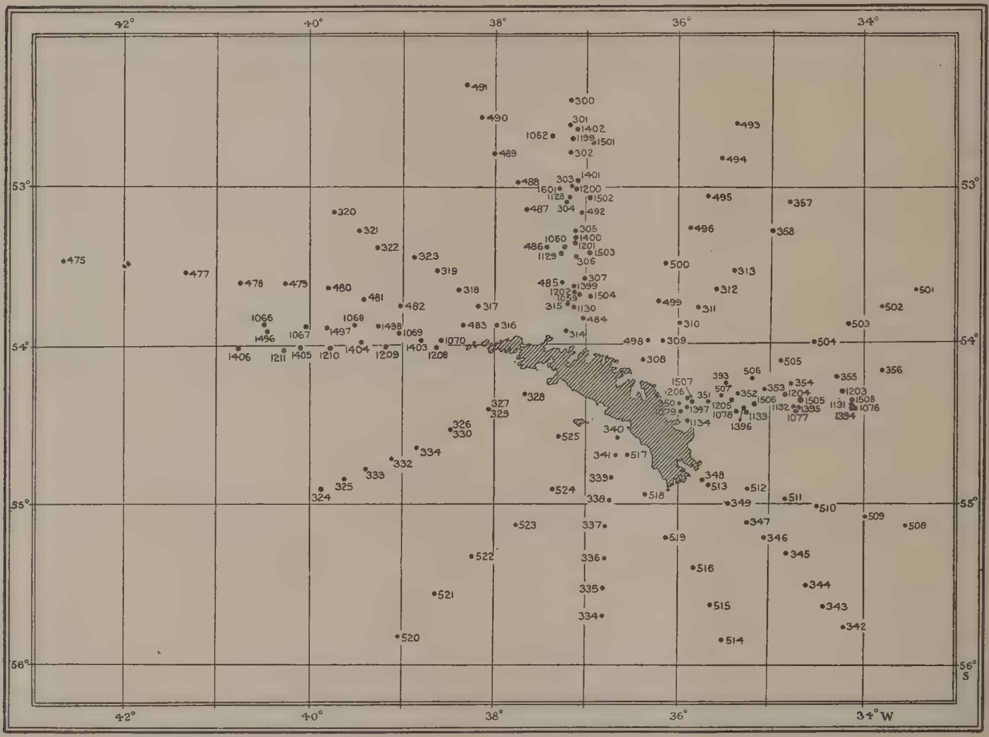
Fig. 4. Positions of stations where observations for phosphate or silicate were made in the sector of the Southern Ocean south of Australia and New Zealand.

convergence and more particularly of the ice-edge vary considerably both with the season and with the year; but the arbitrary regions have been found to agree so well with the types of phytoplankton communities encountered that there is little doubt that they have a real biological significance. There is a very strong possibility that the southern region comprises the area of the East Wind Drift of the Southern Ocean, unless the ice is very far north.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38°
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34° W
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Fig. 5. Positions of stations where observations for phosphate or silicate were made around South Georgia.

Dr Hart further informs me that in the northern region the phytoplankton does not begin to increase very rapidly until the first week in November, when the gradient becomes extremely sharp. By the middle of December the numbers are falling off and the downward gradient of the concentration becomes as sharp as the upward gradient of early November. At the beginning of April the numbers are comparable with the concentration of early November before the large increase; a slight increase was recorded in May. In the southern region, on the other hand, the increase in phytoplankton concentration is never rapid and the maximum is far below that of the northern region. Moreover, the increase starts in the first week of November and carries on until a maximum is reached in the third week of February. A slow decline then sets in to the third week of April, followed by a small autumnal increase in May, after which it declines again. All the dates mentioned above are subject to an annual variation of ± 2 weeks.

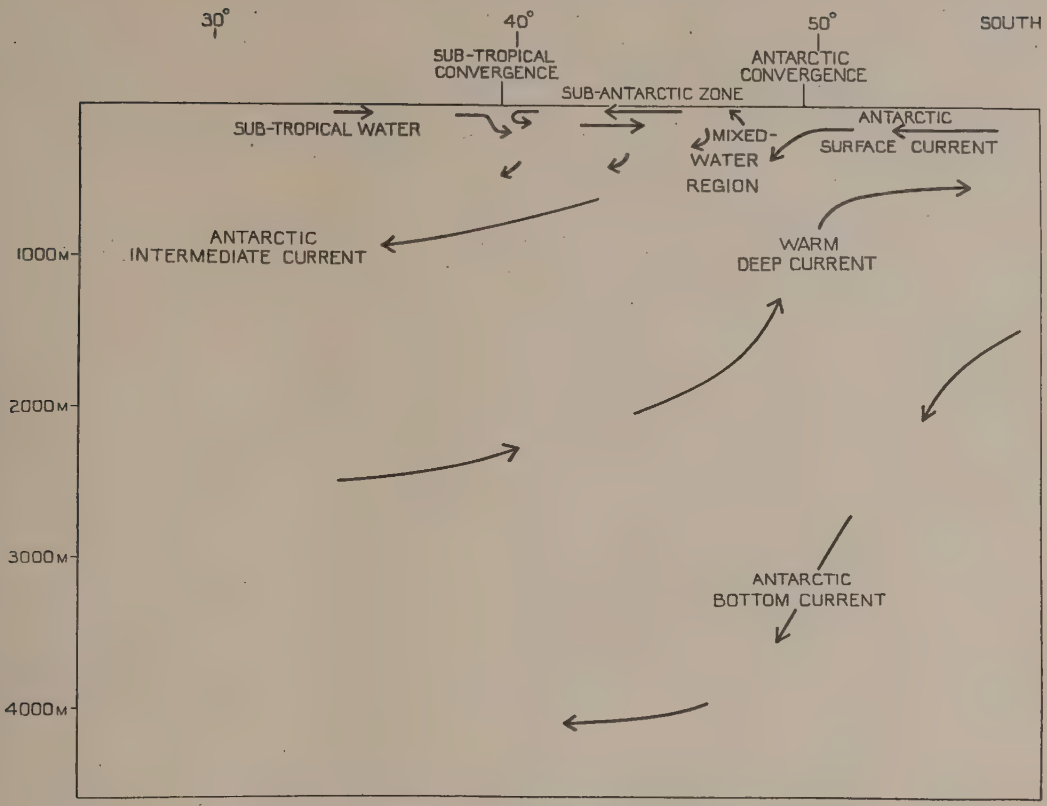
30°
40°
50°
SOUTH
SUB-TROPICAL CONVERGENCE
ANTARCTIC CONVERGENCE
SUB-ANTARCTIC ZONE
SUB-TROPICAL WATER
MIXED-WATER REGION
ANTARCTIC SURFACE CURRENT
ANTARCTIC INTERMEDIATE CURRENT
WARM DEEP CURRENT
ANTARCTIC BOTTOM CURRENT
1000M
2000M
3000M
4000M

Fig. 6. The vertical circulation of water in the South Atlantic Ocean.

THE PHOSPHATE AND SILICATE CYCLES IN THE SOUTHERN OCEAN

It will be advisable to discuss at an early stage of the report the means by which the phosphate and silicate contents of the Antarctic zone are maintained at such high values.

The vertical sections in the plates at the end of this report show that at the surface phosphate varies from a value of about 130 mg. in winter at the ice-edge to zero in the tropical zone. Similarly the silicate content diminishes from values of 3000–3500 mg. at the surface at the ice-edge in winter to zero in the subtropical and tropical zones. These nutrient salts are being continuously lost to the Antarctic zone in the form of plankton or in the free state when the Antarctic surface water, which has a northerly component of movement, sinks into sub-Antarctic water at the Antarctic convergence. Similarly large quantities of both these nutrient salts are carried away northwards out of the Antarctic zone by the Antarctic bottom water. Obviously a return process must exist or the Antarctic zone would be denuded of these salts.

In the western part of the South Atlantic Ocean (section 2) the phosphate cycle is well illustrated by the vertical section in 30° W which is given in Plate IV. In the

Antarctic zone the greatest phosphate content is found in the upper layers of the North Atlantic deep water. North of the Rio Grande ridge in about 35° S the maximum phosphate content is found in the Antarctic intermediate water, and the warm deep water contains less phosphate. Thus the warm deep water is not the source of the high phosphate concentrations which are found in the Antarctic zone. Phosphate is added to the warm deep water south of the Rio Grande ridge, and the source of this phosphate must lie in the rich plankton of the Antarctic zone which decomposes in the Antarctic surface water when it sinks into the bottom of the sub-Antarctic layer. It is probable that the decomposition of plankton is greatest in the region of greatest phosphate content; this occurs between the north-going sub-Antarctic and Antarctic intermediate waters and the south-going warm deep water, between 43° and 38° S. In this region the greatest vertical mixing between these currents also occurs, so that the phosphate, released by the decomposition of plankton, passes over into the mixed water in the upper layers of the south-going warm deep water. In due course it is utilized by the phytoplankton and the cycle recommences.

In the eastern part of the South Atlantic Ocean (section 3) a similar phosphate cycle prevails; this is illustrated in Plate V, which is a section between 69° 20′ S and 3° 46′ N. Maximum phosphate occurs in 41° S at a depth of 1000 m. in the Antarctic intermediate water where decomposition is probably greatest. The phosphate is returned to the south in the mixed water which forms the upper layers of the warm deep water.

The vertical section of phosphate content, between Cape Town and the ice-edge north of Enderby Land in 66½° S, 42½° E (section 4, Plate VII), shows admirably the phosphate cycle in this part of the ocean. Phosphate may be seen leaving the Antarctic zone both in the sinking Antarctic surface water at the Antarctic convergence and in the bottom water. The sinking Antarctic surface water forms part of the Antarctic intermediate current. Between about 40° S and the coast of South Africa the nucleus of this current reaches its greatest depth at 1500 m., as is shown by the salinity minimum at this depth.[1] The reason for this increased depth is the vast bulk of subtropical water brought into the area by the Agulhas current system which depresses the level of the intermediate water. Even at 38° S the phosphate content at the depth of the salinity minimum of the intermediate water is 140 mg., and some of this amount is lost to the phosphate cycle in the upwelling towards the coast of South Africa. The maximum content of phosphate in the whole section is seen at 48° S, where it amounts to 148 mg. between 600 and 800 m. in the upper part of the warm deep water and where it is being returned to the south in this current. North of the Antarctic convergence the sinking Antarctic water is mixing with the upper layers of the warm deep water. Between 45° and 38° S the phosphate content of the warm deep water is much lower. This may be seen in the value of less than 110 mg. at the salinity maximum of the layer at about 2500–3000 m., in contrast with the content of 141 mg. at the nucleus of the intermediate water in 40° S, and of 130 mg. in the bottom water at the same latitude. Thus the phosphate which is lost to the Antarctic in the sinking surface water and the bottom water mixes in at both the upper and lower boundaries of the warm deep water, and this, because of its southerly movement, returns the phosphate to the Antarctic zone. The various stations south of the Antarctic convergence show that the major portion returns in the upper layers of the warm deep water.

---

[1] The distributions of temperature and salinity in most of the sections mentioned are given by Deacon, *Discovery Reports*, XV, 1–124, Plates, I–XLIV.

In the western part of the South Indian Ocean and the Southern Ocean to the south of this area, it has been possible to construct a section between 64½° S and 11½° N (section 6). This has been done by linking up a series of stations taken in May 1934 from the ice-edge north of Enderby Land in 64½° S, 44¼° E as far as St. 1367 in 47° 41′ S, 44° 43′ E and then across the subtropical convergence in the direction of Durban, with a line of stations made in April–May 1935 from north of Marion Island (46° 49′ S, 37° 49′ E) through the Mozambique Channel and northwards to near Cape Guardafui (11° 50′ N, 51° 20′ E). The complete section is shown in Plate X, and the time interval of nearly a year between the two halves of the section is indicated by a break in the iso-lines between Sts. 1370 and 1567. South of 50° S the average depth of the sea-bottom is between 4000 and 5000 m.; at 45° S the sea-bottom has risen to a depth of less than 1000 m. It is this rise to the Atlantic-Indian cross-ridge, on which stands the island group of the Crozets, which in some degree prevents the loss of phosphate from the Antarctic zone in the bottom water. East of the Crozets and west of Kerguelen, however, there is a large gap between the cross-ridge and the Kerguelen-Gaussberg ridge which must allow the passage of bottom water northwards. In our section (Plate X) it is obvious that the cross-ridge has prevented a considerable loss of phosphate towards the north, since in the far south the bottom water has a content of 150–160 mg., whilst north of the cross-ridge in 45° S it is about 135 mg.

Phosphate leaves the Antarctic zone in the sinking Antarctic surface water, which just south of the Antarctic convergence has a content of 122 mg. compared with 160 mg. in the upper layers of the warm deep water in the same position. As far north as about the subtropical convergence in 40½° S the warm deep water has always a greater content than the sinking Antarctic surface water. Between about 40½° S and about 29° S the Antarctic intermediate water has a greater content than the warm deep water; north of 29° S the influence of the North Indian Ocean deep water with its high phosphate content (>160 mg. at 800–1000 m. between 2½° and 7° N) causes the south-going warm deep water to have a greater content than the north-going Antarctic intermediate water. The course of the Antarctic intermediate current may be traced in the closely separated iso-lines in the upper part of the section. Thus in the western part of the South Indian Ocean the phosphate cycle is more complicated than in the South Atlantic Ocean. This is because in the former the North Indian deep water has a very high phosphate content, particularly in its upper part, whilst in the western part of the South Atlantic Ocean for example, the North Atlantic deep water has a much lower phosphate content north of the Rio Grande ridge than has the Antarctic intermediate water. In the western part of the South Indian Ocean there appear to be two localities where decomposition of plankton must be very extensive, since apart from the influence of the North Indian deep water at lower latitudes and a high content in the Antarctic bottom water south of 56° S, maximum phosphate occurs in these two localities; the first lies between the Antarctic convergence and the Atlantic-Indian cross-ridge, and the second at about 38° S, although the significance of the latter position may be affected by the fact that the section is composed of two sets of observations over a year apart and the division lies close to 38° S, i.e. annual variation is possibly the cause of the higher values at St. 1567 at 1500–2000 m. Also it is not yet certain how far south the last traces of North Indian deep water extend in the upper layers of the warm deep water which is mainly of North Atlantic origin south of 20° S (Clowes and Deacon, 1935). The south-going warm deep water rises steeply towards the surface on the northern side of the Atlantic-Indian cross-ridge and continues to rise to the Antarctic convergence. Its upper layers are in contact with the descending Antarctic surface water, and on the southern side of the cross-ridge considerable mortality and decomposition of plankton must occur to account for the high values of phosphate content found there. The regenerated phosphate is then swept to the far south on the upper layers of the warm deep water, so that at the ice-edge in 64½° S the content immediately below the discontinuity between the surface and warm deep currents is 156 mg.

The source of the high phosphate values in the upper layers of the North Indian deep current is at present unknown, and in any event these high values should be checked by other observations.

In the South Pacific Ocean we have only data from the western part between New Zealand and the ice-edge north of the Ross Sea. One section (12, Plate XVII) was made in late winter, September 1932, and the other section (13, Plate XIX) in midsummer, January 1934. Phosphate leaves the Antarctic zone in the South Pacific in two currents: (1) in the Antarctic surface water which sinks at the Antarctic convergence and spreads northwards as part of the Antarctic intermediate current, and (2) in the highly saline bottom water which flows northwards from the far south. The return of phosphate to the south is effected in the mixing processes which take place between the Antarctic intermediate current and the bottom current with the warm deep water. The largest concentrations of phosphate are found in the bottom layers of the intermediate water and the upper layers of the warm deep water. In the South Pacific sector the Antarctic intermediate water is a very strong current, and the boundary between this current and the warm deep water is a thick layer in which maximum decomposition of the plankton is occurring, thus releasing the phosphate which is carried back to the south in the upper layers of the warm deep water. However, as is stated on p. 15 of this report, not all the water in the upper part of the warm deep water reaches the Antarctic zone.

The silicate cycle in the eastern part of the South Atlantic Ocean can be followed by reference to Plate VI. This shows a section from the ice-edge in 69° 21′ S, 9° 33·8′ E northwards to 3° 46·2′ N, 12° 55·1′ W, although north of 12½° S the observations only extend to 1400 m., i.e. just below the intermediate water. Silicate may be seen to leave the Antarctic zone in two ways; the Antarctic surface water sinks at the Antarctic convergence carrying with it silicate up to about 2500 mg. in a free form plus an unknown amount held by the plankton; these amounts of silicate travel northwards in the Antarctic intermediate water. As the Antarctic intermediate current progresses northwards it steadily loses silicate by mixing with the upper layers of the warm deep water, which in this section have a lower silicate content, north of the subtropical convergence, than the intermediate water above them. The course of the northward flow of the Antarctic intermediate water may be traced from salinity measurements, and even as far north as 4° N there still remained about 1000 mg. of silicate at the salinity minimum of this water. Farther north than our section extends more and more silicate must be lost to the intermediate water and transferred to the southward-flowing warm deep layer.

The second loss of silicate from the Antarctic zone occurs in the Antarctic bottom water, which as Plate VI shows had a content greater than 5000 mg. in March 1933 south of the eastern part of the South Atlantic Ocean. In our section some of this loss is prevented by the rise of the sea-bottom from an ocean depth greater than 4000 m. to one of 2633 m. at St. 1160, which is situated on the Atlantic-Indian cross-ridge in 52° 41·5′ S, 14° 30·4′ E. North of this cross-ridge the lower layers of the warm deep water are seen to be returning silicate southwards, and this silicate is carried towards the surface in this current which rises rapidly near the Antarctic convergence. The majority of the silicate present in the Antarctic surface water is undoubtedly returned in the lower levels of the warm deep water which itself does not have a large silicate content but to which silicate is added by mixing at the boundary surface with the Antarctic bottom water.

Between Cape Town and the ice-edge north of Enderby Land in 66½° S, 42½° E, section 4, Plate VIII, passes through a possible gap in the Atlantic-Indian cross-ridge in about 50° S, 30° E and the sea-bottom does not rise above 4000 m. anywhere in our section. Consequently a greater amount of silicate is seen in the bottom observations in this section than was evident in the previous section (3, Plate VI), when the sea-bottom rose to a depth of 2633 m. in 52° 41·5′ S, 14° 30·4′ E. Silicate may be seen to leave the Antarctic zone in the usual manner, i.e. in the sinking Antarctic surface water, and in larger quantities, in the Antarctic bottom water. Mixing at the upper and lower boundary surfaces of the warm deep water transfers silicate to the southward-flowing warm deep water which returns it to the Antarctic zone. Some of the silicate in the Antarctic intermediate current, which at 38° S contains as much as 2750 mg. at the position of minimum salinity in this current, must be utilized by the plankton in the water which upwells on the continental shelf of South Africa and is thus lost to the silicate cycle in the Antarctic zone.

Plate XI shows a section from the ice-edge in 64° 37·6′ S, 44° 16·3′ E to 11° 32·3′ N, 52·03′ E, which is composed of observations made in May 1934 and April–May 1935; a break in the iso-lines at about 39° S indicates the time interval between the two halves of the section. This plate shows the distribution of silicate in the western part of the South Indian Ocean and the Southern Ocean to the south of it (section 6). At the Antarctic convergence the Antarctic surface water sinks below the surface carrying with it between about 850 and 2000 mg. of silicate in its upper and lower surfaces; an unknown amount of silicate, as represented by the plankton, is also contained in the sinking water which progresses northward as part of the Antarctic intermediate current. Even at 7° N there remain over 1000 mg. of silicate at the salinity minimum of this layer. The lower boundary of the intermediate current is in contact with the upper layers of the warm deep current which north of 20° S in this section is composed of North Indian deep water. South of this latitude the warm deep water is mainly composed of water of North Atlantic origin with traces of North Indian deep water appearing in the upper layers. The silicate content of North Indian deep water is much greater than that of North Atlantic deep water, as a comparison of sections 3 and 6 in Plates VI and XI shows. Consequently in our section up the East African coast the warm deep water has always a greater content than the Antarctic intermediate water, in contrast to the section up the eastern side of the South Atlantic where the intermediate water has a greater silicate content north of the subtropical convergence than have the upper layers of the warm deep water. The sinking Antarctic surface water at the Antarctic convergence flows northwards with an initial content of between 850 and 2500 mg. of silicate. By the time this water has reached 7° N there are about 1000 mg. of silicate remaining at the depth of minimum salinity of the layer. The difference between these quantities has been lost to the northward flow of the intermediate water by mixing with the southward flow of the upper layers of the warm deep water.

The circulation of the bottom water between the Weddell Sea and 30° E is such that the tendency of the cold water is to keep to the northern side of the Atlantic-Antarctic basin, whilst a stream of warmer bottom water exists along the edge of the Antarctic continent. A cyclonic circulation has been suggested for the bottom water in this region with temperature evidence for a southward movement in the bottom water in the eastern part of the basin. Sections across the Southern Ocean south of the Indian and Pacific Oceans suggest that the eastward current of water from the Weddell Sea spreads across these oceans without further additions of cold, poorly saline and highly oxygenated water sinking from the continental shelf of Antarctica. East of Enderby Land (50° E) the coldest bottom water is found near the continental shelf, and the temperatures suggest that the westward movement has ceased. Our section (section 6, Plate XI) begins in $44\frac{1}{4}$° E, and it will be noticed that south of 56° S the deepest observations show that the Antarctic bottom water has a silicate content greater than 7500 mg. at 4000 m. It is uncertain, however, how far south of $61\frac{3}{4}$° S this huge amount of silicate is found owing to the absence of deep observations at St. 1361 (64° 37·6′ S, 44° 16·3′ E). In addition to an eastward movement in the bottom water in our section there must also be a northerly component which carries away a large amount of silicate from the Antarctic zone. This amount is, however, very much less in our section than it would be farther towards the east, where a gap exists between the Atlantic-Indian cross-ridge and the Kerguelen-Gaussberg ridge. At St. 1368, in 44° 54·6′ S, 42° 30·1′ E, the sea-bottom has risen from depths greater than 4000 m. to a depth of 955 m., thus effectively cutting off any possible northward flow of bottom water in this longitude. Actually at the station on the southward side of the ridge, St. 1367 in 47° 41·2′ S, 44° 42·7′ E, the deep observations show that at 3000 m. the water is mainly warm deep water which is already carrying back silicate to the Antarctic zone.

South-east of New Zealand two sections (12 and 13, Plates XVIII and XX) are available. The section in Plate XVIII was made in September 1932 and the other, in Plate XX, in January 1934. In these sections the greatest concentration of silicate is always found at the deepest observations. As we have seen in the Southern Ocean south of the Atlantic and Indian Oceans the major portion of the silicate which leaves the Antarctic is returned in the lower layers of the warm deep water. In the Pacific sector the position is more complicated owing to the more complex nature of the deep currents in this part of the ocean, where the intermediate, warm deep and bottom currents are not separated by any well-marked boundaries. Extensive mixing no doubt takes place between these currents, and silicate exchanges undoubtedly occur, but it is quite plain that east of New Zealand as much as 5300 mg. of silicate are found at 3500 m. in the highly saline layer which is travelling towards the north. Deacon (1937, p. 103) has stated that a large part of the current which flows southward between 1500 and 2500 m. north of 50° S in the more central part of the ocean, sinks between 50° and 55° S to mix with the bottom water; this means that a large part of the southward movement does not make the climb to the higher level of the current in the Antarctic zone but returns directly towards the north with the bottom current, carrying with it large amounts of silicate. On the other hand, the observations made across the sub-Antarctic zone in the South Pacific Ocean suggest that the volume of Antarctic intermediate water carried back to the south by the warm deep current is exceptionally large, although Deacon (*loc. cit.* p. 106) states: "It is not safe to assume that all the water at the level of maximum temperature of the deep water north of the Antarctic convergence finds its way into the upper part of the warm deep layer in the Antarctic zone because it usually has too low a salinity; it appears to be part of a southward eddy which is returned to the north with the surface water which sinks at the convergence." In view of the absence of data from lower latitudes in the South Pacific Ocean any discussion of the return of silicate to the Antarctic zone south of the South Pacific Ocean must be deferred.

We have seen therefore that phosphate leaves the Antarctic in the surface and bottom currents either in the free state or, in the surface current, in the form of plankton. North of the Antarctic convergence, decomposition of the Antarctic plankton occurs chiefly in the Antarctic intermediate current, and the phosphate so released is transferred by mixing to the upper layers of the southward-going warm deep water.

Silicate is chiefly lost to the Antarctic zone in the Antarctic bottom water, although large quantities also travel northwards in the surface current. Unlike phosphate, silicate is always at a maximum in the Antarctic zone, where the greatest mortality of phytoplankton occurs. The return of silicate to the Antarctic is effected by means of the warm deep water, to which silicate is transferred by mixing at both the upper and lower boundary surfaces with the intermediate and bottom currents respectively. Since the greater amount is carried out of the Antarctic in the bottom water the major quantity of silicate is returned in the lower portion of the warm deep water.

ANTARCTIC SURFACE WATER

PHOSPHATE CONTENT AT THE SURFACE

In the introduction to this report we saw that as far as the phytoplankton is concerned two very different regions exist in the Antarctic zone. One, the northern region, where the phytoplankton production is enormous and is confined to a relatively brief period of growth and decline, and the second in the southern region, where the production is far less in actual concentration but is spread over a longer period. With these facts in mind we will review the phosphate and silicate contents of the surface water in both the southern and northern regions of the Antarctic zone. The data are presented as surface values and later as mean integral averages of the 0–100 m. layer to satisfy both the biological and hydrological requirements. The photosynthetic layer of the Antarctic surface water is usually a very shallow layer; under ideal conditions it consists of a well-illuminated, shallow layer separated from the rest of the surface layer by a strong discontinuity. Consequently surface values of nutrient salt content are of more importance to the planktologist than 0–100 m. averages. On the other hand, the 0–100 m. averages offer a good picture of the nutrient salt content of the surface layer in the Antarctic zone.

During a cruise across the Southern Ocean south of the South Atlantic Ocean and as far east as 44° E, mainly in the second half of February 1935, the surface phosphate values were as shown in Table I.

Table I

Station	Position	Surface P_2O_5 in mg./m.^{3}
1510	59° 36·9′ S, 26° 57·7′ W	86
1511	61° 34·3′ S, 22° 46·3′ W	94
1513	63° 54·2′ S, 18° 21·2′ W	94
1515	66° 14·7′ S, 13° 50·2′ W	79
1517*	68° 44·7′ S, 09° 20·3′ W	84
1519	66° 31·0′ S, 03° 40·0′ W	82
1521	64° 34·5′ S, 00° 45·8′ E	83
1523	66° 39·2′ S, 05° 28·2′ E	83
1525*	68° 41·8′ S, 10° 34·8′ E	93
1527	66° 57·2′ S, 15° 10·3′ E	99
1529	64° 54·7′ S, 20° 00·6′ E	68
1531	62° 50·0′ S, 24° 28·2′ E	82
1533	65° 24·3′ S, 27° 07·8′ E	82
1535*	67° 18·0′ S, 30° 34·1′ E	98
1537	64° 33·6′ S, 33° 09·4′ E	102
1539	62° 02·1′ S, 35° 54·5′ E	90
1541	64° 26·6′ S, 39° 17·7′ E	106
1543*	66° 29·7′ S, 42° 26·0′ E	72
1545	64° 11·0′ S, 44° 05·1′ E	91
1547	61° 53·4′ S, 40° 29·8′ E	83

* Denotes ice-edge station.

All the above stations were made south of 60° S except St. 1510, and several were at the edge of the pack-ice north of the continent. The phytoplankton catches during this cruise showed that production had begun earlier in the east than in the west, even allowing for the time interval involved in a west to east cruise lasting 20 days. In general terms it may be stated that in the west (Sts. 1510 to 1523) the phytoplankton was evidently not yet at its maximum, in the centre (Sts. 1525 to 1533) the phytoplankton was in much greater quantity and was probably at its maximum, while from St. 1535 eastwards we entered a "grazed down" area. This area was one in which the diatom nets contained large numbers of euphausian faecal pellets, while the actual catch of undamaged phytoplankton organisms was small. The faeces contained numerous diatom fragments, indicating a previous heavy production of phytoplankton which had been consumed by zooplankton. A striking result of an inspection of the surface values is the general lowness of the phosphate having regard to the average high latitude of the stations. Although production of phytoplankton in the southern region does not come to a maximum until the third week in February (±2 weeks) there must have been a steady drain on the available phosphate from November onwards. It must be remembered that in the southern region of the Antarctic zone the phytoplankton production is a long steady process of small concentration, as opposed to the rapid rise and fall of the huge concentration in the northern region.

From these same stations in Table I some idea can be gained of the amount of phosphate that is withdrawn from the surface layer by the phytoplankton. Thus at St. 1543, an ice-edge station in $42\frac{1}{2}$° E, the phosphate content between 40 and 400 m. is uniformly 128 mg., which figure may be taken as a typical pre-production value for the surface layer at the ice-edge. On an average this value is reduced to about 87 mg. at the surface in February, i.e. a consumption of 41 mg. out of 128 mg. or about 32 per cent at the surface at the ice-edge. Exceptionally the consumption at the ice-edge may be greater, at the above station (1543), for example, a consumption of 56 mg. has taken place or a withdrawal of the order of 44 per cent of available phosphate. North of the ice-edge in 20° E the phosphate was even more reduced as the following figures from St. 1529 in 64° 54·7′ S, 20° 00·6′ E show:

Depth m.	0	10	20	30	40	50	60	80	100
P_2O_5 mg./m.^{3}	68	64	64	65	112	120	124	124	124

Thus out of an available 124 mg. throughout the surface layer, as much as 60 mg. or over 48 per cent of available phosphate has been withdrawn at 10 m. through the agency of phytoplankton. This reduction in phosphate content was accompanied by a very large concentration of phytoplankton, and it is of great importance to note that the reduction was confined to a shallow layer from the surface to a depth of 30 m., below which a considerable discontinuity existed. At this station the 0–30 m. layer was undoubtedly the extent of the photosynthetic layer in this high latitude, and it is interesting to note that the value at 10 m. was lower than the surface value. Had a sample been taken at 5 m. it might have shown the seat of maximum utilization of the phosphate.

Some idea of the later autumn phosphate values of the surface water in the southern region near Enderby Land may be had from the results of section 6 in 45° E towards the Crozets in the first half of May 1934 (Sts. 1361–1366, Plate X), and section 7 in late April 1932 (Sts. 855–864, Plate XII). The observations in the Antarctic zone are given in Table II. The two ice-edge stations were made in comparable positions about 18 days apart though in different years. The phytoplankton conditions were very different; at St. 1361 a very small catch was recorded, whilst at St. 855 there was a rich phytoplankton concentration for the time of the year and the latitude. From the above table it is seen that at St. 1361, a station where a poor diatom catch was found, the surface phosphate was as high probably as it is at any time of the year, and the silicate was reduced, whilst St. 855, with a rich phytoplankton, had a low phosphate content in the surface and a silicate content equal probably to the maximum at any season at this latitude. The observed nutrient salt values do not agree either with one another or with the amount of phytoplankton found at each station; it would have been expected that St. 855 would show low values for both phosphate and silicate contents, and St. 1361 high values for each nutrient salt if there were an immediate connexion between nutrient salt concentration and the density of the phytoplankton. However, we can assume that the rich phytoplankton found at St. 855 was due primarily to a localized concentration which was now, i.e. late April, a fraction of its former concentration. This follows because in late April the concentration was large, and therefore it can be argued that at the end of February it must have been greater still unless the April concentration were due to an autumnal outburst; this, however, is unlikely in view of the nature and volume of the catch. The ice-edge phytoplankton is characterized by a long steady growth period from November to the end of March, and, exceptionally, the

Table II

Station	Position	Surface P_2O_5 mg./m.^{3}	Surface SiO_2 mg./m.^{3}
1361*	64° 37·6′ S, 44° 16·3′ E	130	2200
1362	61° 45·5′ S, 44° 15·9′ E	129	2300
1363	59° 14·0′ S, 44° 27·9′ E	120	1600
1364	56° 38·6′ S, 44° 45·4′ E	120	1500
1365	55° 12·8′ S, 44° 52·5′ E	115	1500
1366	50° 42·3′ S, 44° 54·1′ E	122	850
855*	65° 15·0′ S, 48° 43·7′ E	84	3400
856	61° 06·6′ S, 53° 39·8′ E	87	—
857	60° 40·1′ S, 59° 23·7′ E	96	—
858	60° 10·1′ S, 63° 54·8′ E	96	—
859	59° 19·1′ S, 68° 51·8′ E	95	—
860	57° 56·4′ S, 73° 58·8′ E	108	—
861	56° 28·9′ S, 79° 18·2′ E	117	—
862	55° 33·8′ S, 83° 00·4′ E	121	—
863	54° 15·3′ S, 88° 22·4′ E	121	—
864	53° 11·7′ S, 93° 10·6′ E	100	—

* Ice-edge station.

ice-edge is the seat of very large concentrations. Now if at St. 855 a large concentration had been existing for some months previously, it is obvious that a large amount of nutrient salt must have been removed from the surface water during this period. The phosphate value of 84 mg. is sufficiently low to agree with this large withdrawal, provided a pre-production value of about 130 mg. is allowed at the ice-edge. The silicate value of 3400 mg. requires an explanation.

Let us consider the utilization of phosphate and silicate by the phytoplankton. An immediate result is the withdrawal of a high proportion of these salts from the photosynthetic zone of the surface layer. Then follows a consumption of the phytoplankton by the zooplankton, which latter as far as we know does not require much silicate for its nutrition. The zooplankton then excretes the undigested matter including the silica skeletons of the diatoms. We have observed the results of this last process in the area close to the position of St. 855. It can be argued that the zooplankton excretes the greater amount of the silicate which comes to it in the form of its phytoplankton food supply, whereas it utilizes a proportion of its phosphate intake in the formation of phosphoproteins, etc. Thus, temporarily, part of the phosphate originally consumed by the phytoplankton is withheld by the zooplankton, whereas the silicate, or a large proportion of it, is returned to the sea in the form of broken diatom skeletons. How rapid is the re-solution of these skeletons is not known exactly, but a rapid regeneration of silicate must be assumed to explain some of the high silicate values recorded just after phytoplankton maxima. By analogy with the English Channel silicate must be utilized by the plankton more than once in one season (Cooper, 1933). Thus it is probable that the high silicate value in the surface at St. 855 is due partly to regeneration in situ. As will be explained later in this report it is also due to the return to the ice-edge of water of high silicate content at this time of the year (see p. 36). Thus the incidence of a moderately rich phytoplankton at St. 855 with a high silicate content in the surface water is not anomalous. The value of 130 mg. as the phosphate content at the surface at St. 1361 is quite compatible with the negligible amount of phytoplankton present; the silicate value is on the low side, however, for an ice-edge station in late April.

Individual figures of phosphate and silicate contents for any region in different years may vary very considerably, and we have an example of this at Sts. 855 and 1361. The concentrations of nutrient salts preceding the main outburst of phytoplankton must vary from year to year. This follows because the amount of these salts returned to the ice-edge or anywhere in the Antarctic is dependent on the amount of nutrient salts that is lost to the Antarctic zone in previous years. The whole conception of the amounts of phosphate and silicate in the Antarctic zone is qualified by three considerations: the speed of regeneration in situ of these nutrient salts is different, the times of the maximum return to the south must be different, and the concentration of these salts anywhere in the Antarctic must show an annual variation. I have discussed the first consideration earlier in this section. The second consideration follows from the different methods of return of phosphate and silicate, which makes coincidence of the times of return extremely unlikely. Around South Georgia, an area in which we have made more observations than anywhere else, we know there is an annual variation of temperature, salinity and phosphate, and it can be assumed that there are corresponding variations in the open ocean.

In March 1933 the surface phosphate content at the ice-edge south of the South Atlantic Ocean in 9½° E (St. 1154) was 104 mg., whilst about 250 miles north of this position the surface value was 74 mg.; this latter value was, however, accompanied by a much heavier phytoplankton.

We have no actual ice-edge figures south of Australia, but at St. 889 in 61° 44·6′ S, 131° 38·4′ E at the end of May 1932 the surface value was 135 mg., a high winter value. The position of this station was north of the ice-edge, which was in the extremely low latitude of 63° 41·4′ S at this time of the year. The value of 135 mg. is very high, and together with a content of 141 recorded at the ice-edge in 153° 57·2′ W in September 1932 probably represents the extreme value for surface phosphate at the ice-edge in winter; a more usual figure is 130 mg.

South of the Tasman Sea in mid-June 1932 the ice-edge surface value at St. 906 (61° 24·7′ S, 154° 26·2′ E) was 130 mg., but a short distance east at St. 912 (61° 05′ S, 158° 24·5′ E) the corresponding content was only 92 mg. St. 912 was situated in very much shallower water than was St. 906, the respective depths being 991 and 3041 m. The chemical and physical data for the water columns at these stations were very different, and in particular the warm deep water at St. 912 was markedly less saline and had a lower phosphate content and yet was much warmer than at St. 906.

In September 1932 the ice-edge surface value north of the Ross Sea was 127 mg. at St. 956 in 62° 12·8′ S, 158° 11·0′ W. In mid-January 1934 the corresponding station was situated at a much higher latitude owing to the difference of season. The surface phosphate at this station, 1267, in 69° 49·4′ S, 159° 12·6′ W was 82 mg. at a date when phytoplankton production was in full activity and responsible for a large withdrawal of nutrient salt.

In January, February, March and November a large number of observations were made along the Pacific ice-edge from the Ross Sea to 80° W in which longitude there are also data for September and October. In the first half of January 1934 from 77° to 159° W the average ice-edge value of phosphate in the surface was 87 mg., which was also the average of some eighteen stations within 200–250 miles of the ice-edge. In late February to mid-March on the return voyage from west to east at an average latitude slightly higher than the westward cruise, six ice-edge stations gave an average surface phosphate of 88·5 mg., whilst all the stations within 200–250 miles from the ice gave an average value of 88 mg. In the interval between the westward and eastward cruises it is probable that the phyto-plankton of the southern region reached its maximum concentration, but it is doubtful whether the average value for the surface phosphate dropped much below 87 mg., which may represent an average minimum surface value for this region. A comparison of this value with figures for the lower part of the Antarctic surface layer shows that about 30 per cent of the available phosphate is withdrawn by the phytoplankton at the ice-edge of the South Pacific sector of the Southern Ocean.

In the eastern part of the south Pacific in early November 1934 the average ice-edge value for the surface phosphate was about 112 mg., whilst in an area between $66\frac{3}{4}$° and $59\frac{1}{2}$° S and between 80° and $109\frac{1}{2}$° W an average surface value for fourteen stations was 105 mg. This was at a time when the phytoplankton outburst had begun and the phosphate results showed this by the reduction of the ice-edge value to 112 mg.

In 80° W we have ice-edge results from the months of March, September, October and November 1934, but in considering these the effect of the differing latitude of the ice-edge in the various months must be taken into account. Observations were also made in December 1933, but there are good reasons for considering these unreliable and they are not included in the following table which consists of the phosphate data at the ice-edge stations together with the latitude of the stations.

Station	Date	Latitude	Surface P_2O_5 mg./m.^{3}
1312	10. iii. 1934	68° 18′ S	110
1415	12. ix. 1934	63° 40·6′ S	105
1450	30. x. 1934	66° 03·1′ S	120
1472	14. xi. 1934	66° 31·6′ S	112

In March the ice-edge was farthest south and the surface value was still some 23 per cent less than in the bottom of the surface layer. Regeneration has raised the content from a probable minimal value of 85–90 mg. The effect of seasonal variation in the latitude of the ice-edge is best seen in the September and late October figures that for October being greater than the value in September. There was practically no phytoplankton activity in September and not much more in October. The September value was less of course because the ice-edge was far north at this time, but even so the value is considered to be low. The fall from late October to mid-November, during which time the ice-edge retreated a short distance to the south, can be accounted for by the increase of phytoplankton activity.

In January 1931 on a line of stations north and west of Adelaide Island, which is situated in the south-east of the Bellingshausen Sea, the surface phosphate increased from 73 mg. inshore to 104 at the outermost station. The low value near the coast was accompanied by a heavy concentration of phytoplankton.

In late December 1930 off the north-west coast of Graham Land between Anvers Island and Adelaide Island the surface phosphate at three stations was 103, 102 and 93 mg., at a time when the phytoplankton had by no means come to a maximum.

In general terms it may be stated that in the Antarctic zone, when allowance is made for the differing time of the maximum concentration of the phytoplankton across the zone, the phosphate and silicate values at the surface fall from south to north. In the above remarks the surface phosphate content at the southern end of the Antarctic zone has been described as far as our present knowledge allows, and the distribution at the northern end of the zone will now be considered.

In April 1930 (in section 1, Plate III) at St. 384, a position just south of the Antarctic convergence in the Drake Passage, the surface water had a phosphate content of 115 mg., as opposed to a content of 75–82 mg. at the end of December 1933 at Sts. 1234 and 1235. It is obvious that the April figure is showing the effect of regeneration, whilst the December results were obtained after the maximum concentration of phytoplankton in the northern region, and are correspondingly low.

In the Scotia Sea between South Georgia and the Falklands a surface value of 99 mg. was observed in the second week of October 1934; the main outburst of phytoplankton had not yet occurred in this position. Just south of the convergence between the Falklands and Elephant Island the surface had a phosphate content of 98 mg. in late September 1934 (St. 1425), whereas earlier in March 1934 a surface value of 110 mg. was recorded at St. 1326 in the same position. Very poor catches of phytoplankton were taken at both stations; the value of 98 mg. in September would appear to be low. As evidence of an annual variation we have a surface value of only 85 mg. in early March 1931 at St. 634 (in a position very close to that of St. 1425) as opposed to 110 mg. in March 1934.

Immediately south of the Antarctic convergence to the north of the South Orkneys we have data for late January, early April and early October. The surface contents are respectively 76, 113 and 113 mg.; these figures probably approach the limits of the annual range of surface phosphate throughout the year in this position. If this is correct the withdrawal from the surface during the phytoplankton season at the Antarctic convergence is of the order of 37 mg. out of an available 113 mg., about 33 per cent.

In the Scotia Sea, excluding South Georgia which is dealt with later in this report, we have no surface values for the winter months of May, June, July and August. Phosphate is probably maximal in these months unless a southward movement of sub-Antarctic water across the convergence considerably reduces the phosphate content. Consequently in the absence of winter surface values the seasonal range of phosphate just south of the convergence in the Scotia Sea must be given with some reserve. However, it seems clear that a midsummer value of about 75–80 mg. is usual and an autumnal value of 110–115 mg. is to be expected. The value for the winter months may be in the neighbourhood of 115–120 mg.

In the South Atlantic Ocean in 30° W a value of 105 mg. was recorded in early April 1931 for the surface phosphate just south of the Antarctic convergence, whereas in 22° W in mid-August 1934 only 94 mg. were found in the surface. In mid-October 1930 at St. 452 in 49° 50′ S, 08° 32½′ E, which position lies to the north of the easterly drift out of the Weddell Sea, only 79 mg. were found at a time when the main outburst of phytoplankton had not begun.

At the Antarctic convergence north of Enderby Land the surface phosphate was of the order of 85–95 mg. in February and April, whilst in early May 1934 it had risen to 122 mg. On a diagonal course between Enderby Land and Fremantle, Australia, in late April 1932 the surface value was 100 mg. just south of the convergence. In late May 1932 the value farther east, and south of Australia, was 116 mg., whilst south of the Tasman Sea a month later 106–115 mg. were recorded.

At the convergence north of the Ross Sea we have values for the surface phosphate in early September 1932 and the third week in January 1934; these may be regarded as winter and summer values and are 126 and 89 mg. respectively. It may be remarked here that an exceptionally low value of 59 mg. was found south of the position where 89 mg. was recorded in January 1934; this represents a withdrawal of more than 54 per cent of the available phosphate. North-east of the Ross Sea the convergence intersects the ridge which runs between Cape Adare and Easter Island, and a very high value of 143 mg. was found just south of the convergence in mid-September 1932; upwelling is probably the cause of this high value. Farther east during the same cruise values of 110–120 mg. were established just south of the convergence.

In 80° W a routine section was made in 1934 and there are four sets of observations just south of the convergence. These are 112 mg. in mid-March, 107 mg. in mid-September, 103 mg. in late October and 96 mg. in mid-November. In March the 0–60 m. layer was largely composed of sub-Antarctic water which was overlying Antarctic surface water and regeneration in situ had been in full operation for some time past owing to the earlier date of the phytoplankton maximum in the sub-Antarctic zone. The September, October and November figures show that in 80° W in 1934 not much phosphate had been utilized by the phytoplankton up to the date of the November station, and that in this year at least the main outburst did not begin in this longitude until after 16 November. It has been our misfortune to be elsewhere at the time of the main outburst of phytoplankton in 80° W, and thus no estimate can be given of the amount of phosphate withdrawn from the surface.

Thus as a short summary we can say that at the ice-edge in the South Atlantic sector of the Southern Ocean the amount of phosphate withdrawn by the phytoplankton is of the order of 41 mg. out of an available 128 mg. or approximately 32 per cent. Exceptionally as much as 44 per cent has been withdrawn, whilst north of the ice-edge as much as 48 per cent has been utilized.

In the South Pacific sector the withdrawal at the ice-edge amounted to about 30 per cent of the available phosphate, with again greater amounts on occasions north of the ice-edge.

The data for the northern part of the Antarctic zone are far from complete, but the evidence at present suggests that a withdrawal of 33 per cent of available phosphate occurs during the phytoplankton season.

It is suggested that when phytoplankton is consumed by zooplankton the latter incorporates a proportion of the phosphorus content of the plants and excretes most of the silicate content. The excreted silicate is considered to redissolve quickly and thus regenerate in situ whilst there is a distinct lag in the phosphate regeneration.

PHOSPHATE CONTENT OF THE 0–100 M. LAYER

From the foregoing remarks on the phosphate content at the surface in the Antarctic zone it will have been realized how the individual values obtained vary with the season of the year. As a means to a better understanding of the phosphate content of the Antarctic water the mean integral values for the 0–100 m. layer have been calculated.

The mean value between 0–100 m. has been selected because this layer with very few exceptions consists of true Antarctic surface water unmixed with the upper layers of the warm deep water. The mean values so obtained were averaged over two-monthly periods and plotted against the various months of the year. Having regard to the considerable differences in the actual phosphate content across such a large area as the Antarctic zone which stretches from the ice-edge to the Antarctic convergence, together with the differences in the concentrations of phytoplankton throughout the zone, it was decided to draw two seasonal curves: one, the curve for the northern region constructed from the results of stations within a distance of 300 miles south of the Antarctic convergence; the second, a curve for the southern region made from values at stations within 200 miles of the ice-edge. These curves are shown in Fig. 7; the numbers opposite the points on the curves give the numbers of observations from which each two-monthly average is calculated. No curve has been constructed for the area between the southern and northern regions of the Antarctic zone because at present our observations in this area are not sufficiently numerous.

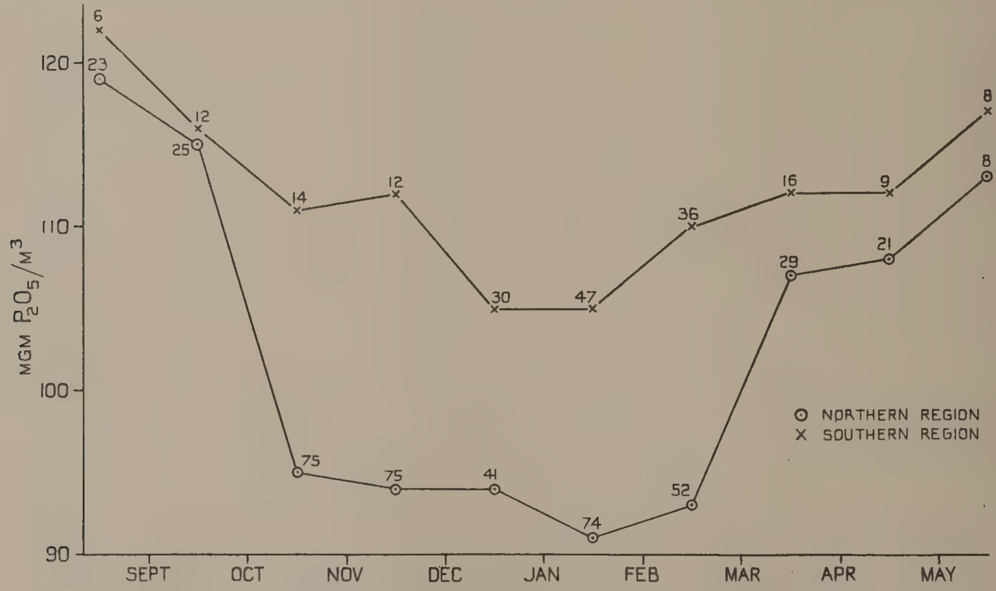

Fig. 7. The average phosphate contents of the 0–100 m. layer in the southern and northern regions in the Antarctic zone of the Southern Ocean.

In the curve for the southern region it will be noticed that the average phosphate content of the 0–100 m. layer falls from August to the end of October, then rises slightly during November, falls again to mid-January and then rises until the end of May. We have no results for July, and consequently the June–July and July–August averages cannot be calculated. The January–February average is very slightly lower than that for December–January, so that the true position of the minimum is reached about the end of January.

In the curve for the northern region the average phosphate content falls from August to the end of January and then rises to 1 June; the fall from August is very steep until 1 November, after which a nearly flat curve results until January when the gradient becomes steeper only to rise subsequently very steeply in March.

The steep fall in the southern curve from August to the end of October is entirely at variance with the observed phytoplankton concentration in this area; the fall of phosphate content is taking place over a period when phytoplankton activity is practically nil and must be due to the effect of the arrival in the southern area in earlier months of water of relatively low phosphate content in the upper layers of the warm deep water.

The fall of 20 mg. during October in the northern curve is a little early for the time that Dr Hart considers to be the average for the main phytoplankton outburst. However, it has been previously stated that the dates of the main outburst of the phytoplankton and its duration are average dates subject to ±2 weeks. In a private communication from Dr Hart the big rise of phytoplankton concentration is shown as apparently beginning in October, but the exact date is uncertain. It will be noticed in the northern curve that the low level of phosphate content persists from 1 November to 1 March, a period of 4 months, with a distinct minimum at the end of January. We know from phytoplankton data that in the northern region effective phytoplankton production lasts from November to December, that the phytoplankton concentration is falling off rapidly from mid-December onwards, and that by 10 April it is back at the figure prior to the main outburst of November. Most of the fall in phytoplankton concentration occurs from the last week of December to the third week of January. Thus the period of 4 months when the phosphate content remains low overlaps the time of effective phytoplankton production. This overlap may perhaps be explained by the arrival in the northern region of surface water from the southern and intermediate regions in which phytoplankton has been continuously removing nutrient salt from November to April, and thus the period of low phosphate content in the northern region is lengthened beyond that which is due to phytoplankton production in situ.

The rise during November, which interrupts the fall in the southern curve from August to mid-January, is interesting because phytoplankton production is starting in November in this area and phosphate should be withdrawn, but apparently it is not until December and January that the effect of production is correlated with a downward gradient of the phosphate curve. The reason for the rise during November must be sought in the northern curve. In the northern curve the minimum occurs at the end of January, after which regeneration causes the phosphate content to rise. After the Antarctic surface water leaves the Antarctic zone it travels with a northerly component as part of the Antarctic intermediate current (see Fig. 6). Vertical sections in the South Atlantic Ocean for example, show that at about 38°–43° S the phosphate content is a maximum in the mixed water between the Antarctic intermediate current and the warm deep water. This mixed water forms the warmer and less saline part of the warm deep water and travels southward as the upper layers of this current. At the Antarctic convergence the warm deep current climbs steeply and its upper layers are found in the southern region of the Antarctic zone at a depth of about 100–150 m. from the surface. Vertical mixing must then be responsible for enriching the Antarctic surface layer in the far south. In this manner phosphate which originally left the Antarctic in the surface layer and in its plankton is returned to the far south to begin the phosphate cycle again. Obviously the amount of phosphate returned to the south must vary both seasonally and annually, and if one considers the phosphate curves for both the southern and northern regions it follows from what has been said of the cycle that the southern curve must show changes corresponding to those in the northern curve. Earlier in this section the fall in the southern curve during August, September and October was noted as being at variance with the lack of phytoplankton activity, but the fall during this period may be an echo of the low phosphate content of the northern region during November, December and January. The rise in the southern curve of November may be related to the rise in the northern curve for February, and thus the northern region minimum at the end of January is reflected in the intermediate minimum at the end of October in the southern curve.

During December the southern curve shows a fall in phosphate content of 7 mg., whereas the northern curve for March shows an increase of 14 mg.; these values do not appear to agree with the previous suggestion that the southern curve will mirror the northern one. However, in the far south phytoplankton production is increasing steadily in December until a maximum is reached in the third week of February. This increase in concentration is accompanied by a withdrawal of phosphate which causes the average of the 0–100 m. layer to fall. The extent of this fall is probably masked by the arrival at the southern region of warm deep water; this contains the regenerated phosphate from Antarctic surface water; this when it left the Antarctic zone in March or later on the northern part of the phosphate cycle, was continuously increasing in phosphate content.

The date of the minimum value in the southern region towards the end of January appears to be early when the date of the peak production of phytoplankton is considered; this occurs in the third week of February, and it would have been expected that the phosphate minimum would have occurred at this time or even later if a time lag existed. If, however, our supposition that an invasion of the area by water of high phosphate content complicates and masks the extent of the fall of phosphate owing to production in situ, it is possible that the position of the true minimum is also altered; phytoplankton requirements would cause this minimum to occur in late February, but prior to this additions are made of water of high phosphate content which change the actual position of the minimum. The water with a high phosphate content seems to arrive at a time when the southern region phytoplankton is coming to a maximum and the changes in the northern region appear to be reflected in the southern region after 9 months, or possibly 1 year and 9 months.

To summarize the above section it may be said that the 0–100 m. average phosphate contents of the surface water have been plotted as 2-monthly means for two arbitrarily chosen regions in the Antarctic. The two curves for these regions differ slightly; that for the southern region falls in general from September to the end of January and rises from February to the end of May, whilst the northern curve falls steeply from September to November, then falls very slowly to a minimum at the end of January and rises steeply to the end of May. These rises and falls cannot always be attributed to phytoplankton activity *in situ*, and it is suggested that the two curves are interrelated and mirror the effect of phytoplankton activity in the past.

SILICATE CONTENT AT THE SURFACE

The surface silicate contents at a series of stations made in February 1935 across the Southern Ocean south of the South Atlantic Ocean and as far east as 44° E are given in Table III. The phytoplankton conditions during the time these stations were made have been discussed on p. 17 of this report. At the ice-edge in the region of 10° W the surface silicate value is 3200 mg., whilst towards the east the corresponding content falls slightly until in 42½° E it is 2700 mg. Bearing in mind that during this cruise phytoplankton production began earlier in the east than in the west it is reasonable to postulate an ice-edge content of the order of 3000–3500 mg. for the surface, at least between 10° W and 42½° E, before the main outburst of phytoplankton production. At no station on the ice-edge anywhere around the Antarctic Continent has the surface silicate content exceeded 3500 mg. at any time of the year. It is difficult to obtain an accurate estimate of the amount of silicate withdrawn from the surface at the ice-edge

Table III

Station	Position	Surface SiO_2 mg./m.^{3}
1510	59° 36·9′ S, 26° 57·7′ W	3300
1511	61° 34·3′ S, 22° 46·3′ W	3450
1513	63° 54·2′ S, 18° 21·2′ W	3050
1515	66° 14·7′ S, 13° 50·2′ W	2450
1517*	68° 44·7′ S, 09° 20·3′ W	3200
1519	66° 31·0′ S, 03° 40·0′ W	3000
1521	64° 34·5′ S, 00° 45·8′ E	3150
1523	66° 39·2′ S, 05° 28·2′ E	3150
1525*	68° 41·8′ S, 10° 34·8′ E	3150
1527	66° 57·2′ S, 15° 10·3′ E	3000
1529	64° 54·7′ S, 20° 00·6′ E	750
1531	62° 50·0′ S, 24° 28·2′ E	1800
1533	65° 24·3′ S, 27° 07·8′ E	1600
1535*	67° 18·0′ S, 30° 34·1′ E	2800
1537	64° 33·6′ S, 33° 09·4′ E	2250
1539	62° 02·1′ S, 35° 54·5′ E	2100
1541	64° 26·6′ S, 39° 17·7′ E	2550
1543*	66° 29·7′ S, 42° 26·0′ E	2700
1545	64° 11·0′ S, 44° 05·1′ E	2100
1547	61° 53·4′ S, 40° 29·8′ E	1850

* Denotes ice-edge station.

by the phytoplankton owing to lack of data at the critical time. Thus at St. 1535 there must have been a heavy phytoplankton concentration immediately previous to the time when the station was made, i.e. the position of the station was in the "grazed down" area which has been discussed on p. 17 of this report. At this station the surface value of silicate was 2800 mg. at a time subsequent to a peak concentration of phytoplankton. At the depth of the cold nucleus of the surface layer the value was 3000 mg. We know from the character of the phytoplankton catches at this station that conditions for the regeneration of silicate were ideal. The difference between the surface and cold nucleus values of silicate content will only give a minimum amount of silicate withdrawn by a previous phytoplankton maximum because most probably regeneration of silicate in situ has been taking place. Examination of all the ice-edge data from stations made during 1933–5 has shown that the minimum net withdrawal of silicate by phytoplankton as calculated from the difference between the surface and cold nucleus contents varies from month to month. The minimum net withdrawal varied between about 0 and 1000 mg. of silicate in the months of September onwards to May, being greatest in the summer months.

North of the ice-edge, however, very much larger amounts of silicate are withdrawn from the surface by phytoplankton requirements. At St. 1529 (64° 54·7′ S, 20° 00·6′ E), some 250 miles north of the pack-ice a value of only 750 mg. was found in the surface, whilst at a depth of 100 m., in the bottom of the surface layer, about 3000 mg. were recorded. This low surface value of silicate was accompanied by a very large concentration of phytoplankton. Thus north of the ice-edge the silicate content at the surface may be withdrawn to an extent of 75 per cent of the available silicate in exceptional circumstances. It is interesting to note that at this station the surface phosphate was also found to have been greatly reduced to an extent of 48 per cent of the available phosphate. During this cruise of late February 1935 the average position of the ice-edge between 10° and 30° E was about 68° S; at a latitude of 65° S in this sector the average silicate content of the surface was 1550 mg. Thus, although exceptionally as much as 75 per cent of the available silicate may be withdrawn by phytoplankton activities in 65° S, a more usual value of the consumption is about 50 per cent. The fact that the apparent net consumption at the actual ice-edge is lower than at 250 miles farther north is interesting. According to Dr Hart it may be stated that the ice-edge does not generally support such a large phytoplankton concentration as exists 250 miles farther north. Consequently the silicate consumption at the ice-edge should be lower than farther north.

From Table III on p. 27 it might be inferred that the surface silicate content falls from west to east in the high latitudes of the Southern Ocean from 30° W to 44° E. In early May 1934 a line of stations was made from 58° 43·3′ S, 16° 38·1′ E towards the ice-edge in 64° 37·6′ S, 44° 16·3′ E. This section cuts diagonally across the eastern side of the area referred to above; by inspection of the silicate content in the bottom of the surface layer some slight evidence is obtained of a small fall in silicate content from west to east. However, since our observations across this zone have not been made at a time previous to the season when the phytoplankton begins to increase in concentration, it is not possible to draw definite conclusions at present.

An examination of the phytoplankton found in mid-April 1932 at St. 855 which was situated on the ice-edge in 65° 15′ S, 48° 43·7′ E, gives some evidence of a possible southerly movement of surface water in the eastern part of the area. Dr Hart has examined the phytoplankton at this station, and he informs me that it is of a type which was found in February 1935 in a position 63–64° S, 20–30° E, and its concentration was about one-third of that found in February. A surface silicate value of 3400 mg. at St. 855 indicates that considerable regeneration had taken place. Deacon (1937, p. 28) suggests that the surface cyclonic movement comprising the west-going surface current in the south of the Weddell Sea, the northward movement up the east coast of Graham Land and the easterly current of Weddell water across the Atlantic-Antarctic basin, may be completed by a southward surface movement in 20°–40° E, although the temperature and salinity observations do not give much evidence for such a movement. The question remains whether the appearance of the phytoplankton at St. 855 is due to some such southerly surface movement, which, coming from 63°–64° S in 20°–30° E in February, is found in 65¼° S, 48¾° E in mid-April. The value of 3400 mg. for the surface silicate at St. 855 indicates that regeneration has taken place, and this might have occurred during such a possible southerly movement. In this event it is possible that the southerly movement in the surface layer extends farther to the east than 20°–40° E, and the phytoplankton found at St. 855 in mid-April in 65¼° S, 48¾° E would be a remnant of an earlier concentration which existed in 63°–64° S. It may have been carried to the east from 20°–40° E in the southerly part of the West Wind Drift, before getting into a southerly movement in 40°–50° E. An alternative explanation is that spores from the February diatoms in 63°–64° S sank below the surface layer and travelled southwards on the top of the warm deep water, eventually causing a late outburst on the ice-edge in mid-April in 48¾° E.

We have no silicate data for the southern region of the Antarctic zone between 48° E and 130° E. At the ice-edge in late May 1932 in 63° 41·4′ S, 130° 07′ E (St. 887), the surface silicate was 2680 mg. at a time when the phytoplankton was very poor. At this station the warm deep water was as close to the surface as 80 m., but even so, the surface layer was definitely poorer in silicate than at a corresponding position south of the South Atlantic Ocean. The value of 2680 mg. may represent the maximum content of the year in this position.

There are no observations for silicate content south of the Tasman Sea, but in the Southern Ocean south of the Pacific there are many data, including figures for the months of January, February, March, September, October, November and December, mostly in 1934. The observations range from 171½° W to 77° W, and thus the results constitute a good picture of the ice-edge conditions in summer, early autumn and spring. In September 1932, at the ice-edge north of the eastern entrance to the Ross Sea, the surface silicate content was 2000–2500 mg. at about 61½° S. Although the ice-edge is far north for September in this position the main outburst of phytoplankton had not taken place and the concentration was very small. On the other side of the Pacific, in 78° W, at St. 1415 in September 1934, the silicate value at the ice-edge in 63° 40′ S was 1150 mg., a figure the order of which is corroborated by one of 1000 mg. for the surface silicate at St. 974 in late September 1932 in 63° 57′ S, 101° 16′ W. At none of the above stations was there any evidence of the main outburst of phytoplankton having begun. It will be seen that the silicate content of the surface water diminishes from west to east. This fact was amply confirmed by the ice-edge cruises of December–January 1933/4 and February–March 1934 across the Southern Ocean south of the Pacific. During both these cruises the surface content of silicate at the ice-edge diminished from west to east as shown by the following table:

Westward Cruise

W longitude	77° 05′	77° 51′	98° 10′	114° 46′	129° 27′	135° 54′	153° 41′	159° 13′
Surface silicate	1950	2100	950	2250	2050	2050	2400	2600

Eastward Cruise

W longitude	79° 34′	97° 04′	129° 16′	145° 52′	171° 26′
Surface silicate	1750	1150	2550	1400	2275

It is not only the ice-edge stations which show that the silicate content of the surface water increases from east to west in this area. The 0–100 m. averages have been calculated for all stations within 250 miles of the ice-edge and are shown plotted against longitude in the graph below in Fig. 8. It may be seen that apart from several fluctuations the silicate content of this layer rises from east to west in both the westward and eastward cruises. In the west the silicate content in mid-January is greater than in late February, a fact which is directly connected with the time of the phytoplankton maximum in this area. In mid-January the phytoplankton had not yet attained its maximum concentration in the west, whereas in late February the observations were made during the time of the maximum. Also in the east near 80° W the time of the main phytoplankton outburst has been found to be earlier than in the far west. At the end of the eastern cruise in the second week of March the phytoplankton maximum was passed in 80°–100° W, and regeneration of silicate had set in with the result that the values in March were greater than those in December. The reason why the surface layer is richer in silicate in the west than in the east in the far south of this part of the Southern Ocean lies in a difference in level of the warm deep water on the two sides of the ocean and also in the fact that the warm deep water in its passage across the ocean from west to east loses silicate by mixing with other layers. In the west the warm deep water climbs steeply towards the surface when near the Antarctic convergence, and in the east more gradually; the result is that in the Antarctic zone the maximum temperature of the warm deep water lies at a depth of about 300 m. in the west and about 600–800 m. in the east. Silicate returns to the Antarctic mainly in the lower layers of the warm deep water, and thus if this layer is closer to the surface in the west than in the east more silicate will be transferred to the surface layer by boundary mixing in the west than in the east. Also the warm deep water as it passes eastwards across the South Pacific Ocean is modified by the addition of less saline and poorly oxygenated water from the north, which may have the effect of reducing the silicate content of the layer towards the east.

Close to 80° W the silicate content of the surface water varies very considerably with the time of year. It must also be remarked that there is a seasonal variation in the latitude of the ice-edge which is not without effect on the silicate content in this region. In 1934 the minimum amount was found in September when no phytoplankton activity was apparent and when the ice-edge was farthest north. This minimum in September is entirely contrary to expectation and also contrary to the 0–100 m. averages for the southern region of the Antarctic zone. The positions and surface values of the various ice-edge stations close to 80° W are given below.

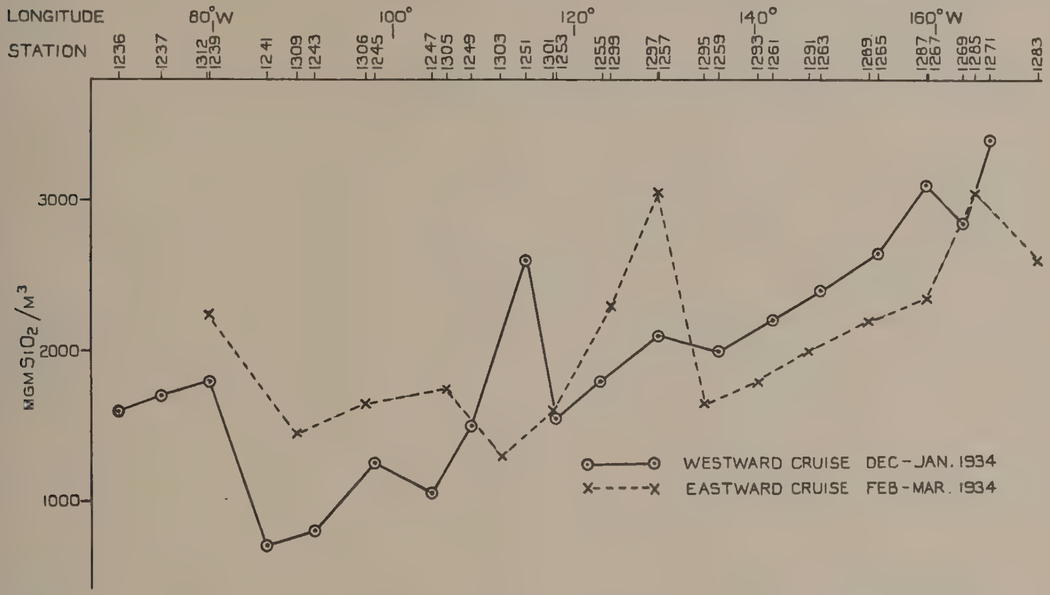

Fig. 8. The average silicate contents of the 0–100 m. layer in the westerly and easterly cruises of the ice-edge region in the South Pacific sector of the Southern Ocean.

Date	Station	Position	Surface SiO_2 mg./m.^{3}
December 1933	1220	67° 45·3′ S, 77° 50·6′ W	2100
January 1934	1238	67° 29·1′ S, 77° 05′ W	1950
March 1934	1312	68° 18′ S, 79° 33·8′ W	1750
September 1934	1415	63° 40·6′ S, 78° 03·5′ W	1150
October 1934	1450	66° 03·1′ S, 79° 42·2′ W	2000
November 1934	1472	66° 31·6′ S, 81° 18·4′ W	1475

The low values of September and November 1934 require further confirmation before any discussion on the seasonal variation in silicate at the ice-edge in this position can be attempted, although in late September 1932 at St. 974 in 63° 57′ S, 101° 16·0′ W, a position just north of the ice-edge but west of 80° W, the surface content of only 1000 mg. appears to confirm the low values referred to above.

In general our knowledge of the surface value of silicate content at the ice-edge is restricted to the Scotia Sea, 10° W to 44° E and 80° to 170° W. The maximum amount of silicate present in the surface at the ice-edge appears to be of the order 3000–3500 mg. The minimum net withdrawal of silicate in this position varies with the season of the year and is between 0 and 1000 mg., being greatest of course in the season of maximum phytoplankton concentration.

North of the ice-edge but still in the arbitrarily defined southern region of the Antarctic zone greater amounts of silicate are withdrawn from the surface by phytoplankton requirements. An average value of 50 per cent of the available silicate is withdrawn, and exceptionally on occasion as much as 75 per cent has been observed.

The silicate content in the southern region of the South Pacific sector of the Southern Ocean is much lower than in the South Atlantic-South Indian sector. The silicate content in the South Pacific sector falls from west to east at the ice-edge, and in the southern region for both the surface and 0–100 m. layer values. This fall in silicate content from west to east is connected with a difference in the level of the warm deep water on the two sides of the ocean. A large proportion of the warm deep water in the South Pacific belongs to a current of North Atlantic and North Indian deep water which enters the Pacific south of Australia. Silicate is lost to this current by mixing during its passage eastwards, and this is reflected in the fall of the silicate in the surface water from west to east.

We must now pass on to consider the silicate content of the surface in the northern part of the Antarctic zone.

In the north of the Antarctic zone, just south of the Antarctic convergence, considerably less silicate exists at the surface than in the south of the zone at the ice-edge. At the northern boundary of the Scotia Sea between South Georgia and the Falklands an observation was made in mid-October 1934 just on the southern side of the convergence. At this position, St. 1439, the surface silicate content was 750 mg. at a time when the phytoplankton concentration was not great.

At the western boundary of the Scotia Sea the surface value in late December 1933, at St. 1234, was 450 mg., but there are indications of the presence of a mixture with sub-Antarctic water in the 0–20 m. layer at this station. Just south of St. 1234 a value of 950 mg. was recorded in typical Antarctic surface water at a time when the phytoplankton concentration was fairly high.

South of the Antarctic convergence in the Scotia Sea between the Falklands and Elephant Island two observations were made in late March 1934 and late September of the same year; these were 850 and 900 mg. respectively at Sts. 1326 and 1425. At both stations a very small concentration of phytoplankton was present. The March value is undoubtedly showing the effect of regeneration, but the September figure is rather low for such a position at a time previous to the main outburst. North of the South Orkneys there are three observations south of the convergence which are shown below. The silicate values are those for the surface and lower part of the Antarctic surface layer.

Station	Position	Date	SiO_2 mg./m.^{3}	
			Surface	Cold nucleus
1495	52° 05·6′ S, 44° 05·3′ W	25. i. 1935	<300	1100
1337	52° 25·1′ S, 44° 09·6′ W	7. iv. 1934	350	1050
1434	52° 16·3′ S, 45° 21·4′ W	3. x. 1934	1050	1200

The values in the above table show that during the summer a very large proportion of the available silicate is utilized by the phytoplankton. In this connexion it should be noted that the value of <300 mg. in late January was obtained at a time considerably later than the date of the maximum concentration of the phytoplankton, and it is possible that in mid-December in this position the surface silicate content was even less than that recorded in late January. The value of 1050 mg. was obtained immediately prior to the time of the main outburst of phytoplankton.

Thus, just south of the Antarctic convergence in the Scotia Sea, the surface silicate content in 1935 was reduced during the phytoplankton season from a pre-outburst value of the order of 1050 mg. to probably well under 300 mg., a utilization of at least 75 per cent of the available silicate. The concentration of phytoplankton which the Scotia Sea supports is, of course, very high.

Outside the Scotia Sea near the Antarctic convergence in 22° W a surface value of 1150 mg. was recorded in Antarctic water in late August 1934 at St. 1390, 51° 30·5′ S, 22° 14·6′ W. The order of this value compares with the surface content just south of the convergence in the Scotia Sea previous to the main phytoplankton outburst.

South of the Antarctic convergence north of Enderby Land the surface silicate varied considerably from year to year as the following results show:

Station	Date	Position	Surface SiO_2 mg./m.^{3}
850	15. iv. 1932	50° 43·8′ S, 31° 44·0′ E	2400
1160	18. iii. 1933	52° 41·5′ S, 14° 30·4′ E	2000
1366	14. v. 1934	50° 42·3′ S, 44° 54·1′ E	850
1552	6. iii. 1935	51° 11·0′ S, 32° 55·2′ E	1000
1560	3. iv. 1935	51° 08·9′ S, 23° 55·3′ E	950

Sts. 850, 1160 and 1560 were situated immediately to the north of the cold easterly current which flows across the South Atlantic from the Weddell Sea; this current appears to have a high silicate content at the surface. It is possible that in the early autumn months of 1932 and 1933 the water at Sts. 850 and 1160 was more influenced by the Weddell Sea current than in April 1935 at St. 1560, or else, owing to a difference in time of the phytoplankton outburst in the different years, regeneration began earlier in 1932 and 1933 than in 1935. On the other hand, values of surface silicate content greater than 2000 mg. in the autumn close to the Antarctic convergence are unusual as far as our present data show. At no other station in a corresponding position were figures of this magnitude obtained at any time, although no winter values are available. However, until more data are obtained of silicate content in and just north of the easterly current of Weddell water, it is not possible to reject these values of over 2000 mg. South of Australia in late May 1932 the surface content was only 460 mg. at the northern boundary of the Antarctic zone. The value in this position when compared with that of 2400 mg. in mid-April 1932 in a corresponding position north of Enderby Land is very small.

In the South Pacific, north of the Ross Sea, two observations south of the Antarctic convergence give summer and winter values. St. 1275, 59° 29·2′ S, 170° 01·8′ W, in late January 1934 had a surface value of less than 200 mg., whilst St. 950, 59° 05·3′ S, 163° 46·5′ W, in early September had a surface value of 800 mg. The very small amount of silicate in the 0–60 m. layer at St. 1275 was corroborated by a similarly small value found 3° farther south a day earlier, when in the 0–30 m. layer there was less than 200 mg. present compared with over 2000 mg. in the bottom of the surface layer at 100 m. These summer values north of the Ross Sea indicate that within the photosynthetic layer near the Antarctic convergence the silicate content falls very considerably to a value which may be limiting for phytoplankton requirements.

Towards the eastern side of the South Pacific the surface values south of the convergence varied in September between 800 and 1400 mg. In 80° W five observations were obtained as follows:

Date	Surface SiO_2 mg./m.^{3}
15. xii. 1933	900
12. iii. 1934	300
13. ix. 1934	1150
29. x. 1934	1150
16. xi. 1934	1050

The September, October and November values indicate that phytoplankton activities had not begun to have much effect on the silicate content of the surface water by the middle of November. We have no observations at the time of the peak concentration of phytoplankton, but the silicate content at the surface must fall below 300 mg. in this position. If we accept a value of about 1200 mg. as a pre-outburst value, the silicate withdrawal at the peak concentration of phytoplankton must be of the order of 75 per cent of the amount available.

The silicate data at present available for the surface water at the northern part of the Antarctic zone are relatively few, but they show that the percentage of silicate withdrawn by the phytoplankton is large. In general it may be said that much less silicate exists in the surface layer at the northern end of the zone than at the ice-edge. It is estimated that in 1935 about 75 per cent of the available silicate was utilized during the phytoplankton season near the Antarctic convergence north of the South

Orkney Islands. North of the Ross Sea in 1934 the available data indicate that even greater amounts of silicate were withdrawn and that the extent of the withdrawal may have been limiting for the continued growth of phytoplankton.

SILICATE CONTENT OF THE 0–100 M. LAYER

The 0–100 m. averages of silicate content have been calculated for a large number of stations in the Antarctic zone, and two seasonal curves have been drawn from two-monthly means. One, the curve for the southern region, was constructed from the results at all stations within 200 miles of the ice-edge and the other, the curve for the northern region, from observations at all stations within 300 miles south of the Antarctic convergence. The two curves are shown in Fig. 9. We have no results for June and July, so that the seasonal curves are not quite complete.

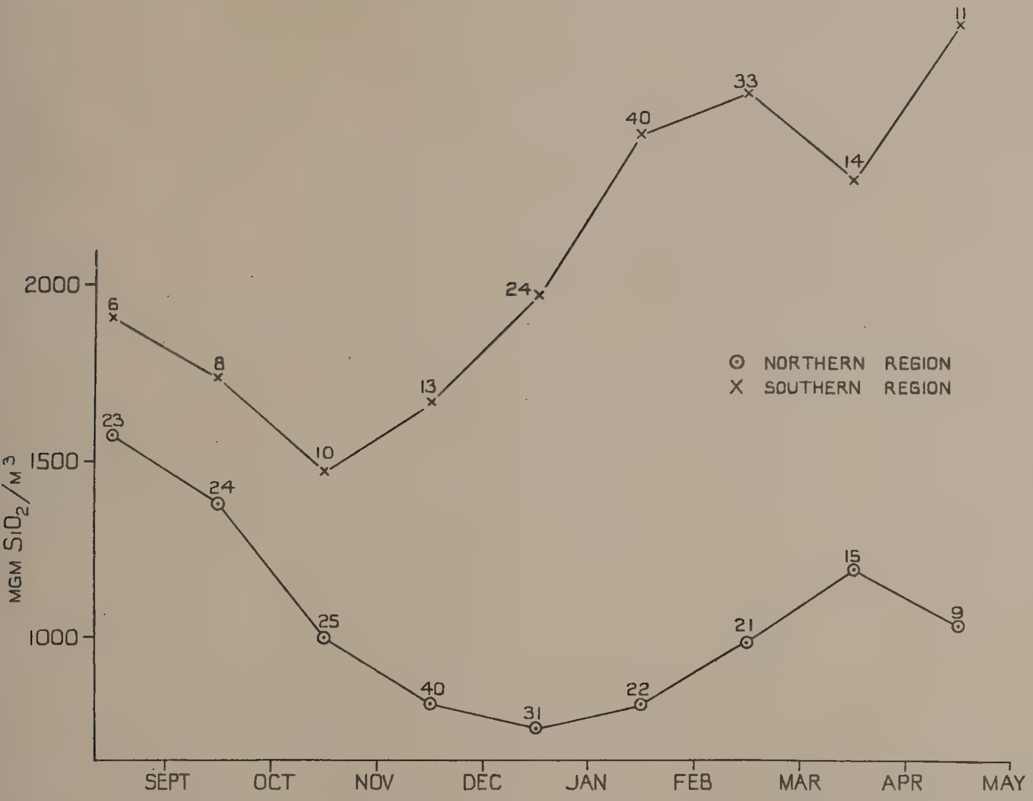

Fig. 9. The average silicate contents of the 0–100 m. layer in the southern and northern regions in the Antarctic zone of the Southern Ocean.

The following features of the southern curve are worthy of notice. A steep fall occurs from 1 September to 1 November, followed by a steep rise from 1 November to 1 February, after which during February the rise is less pronounced; in March a fall occurs, but in April the rise begins again.

The steep fall from 1 September to 1 November and the sharp rise from 1 November to 1 February are both at variance with and opposite to the known effect of phytoplankton production in situ. In the southern region there is no effective production before the first week in November, and then the concentration and the gradient of the increase are small. This phytoplankton production reaches a peak in the third week of February and falls slowly to the third week in April, when a small autumnal rise takes place until the end of the first week of May. Therefore the fall in silicate content from September to November is occurring at a time when no phytoplankton is being produced; similarly the rise of silicate from November to February is taking place at a time when silicate is being utilized by a production of phytoplankton. Only the flattened gradient of the rise in February agrees to some extent with the peak period of phytoplankton concentration. The fall of silicate in March is occurring at a time when the phytoplankton concentration is slowly diminishing.

During the circumpolar cruise of the southern winter of 1932 it was noticed on at least two occasions that there was no movement towards the north across the Antarctic convergence of Antarctic surface water. There was, on the contrary, evidence for a southerly flow of warmer water which is probably a winter feature explained by the fact that the northerly flow in summer, having its origin in melting ice to the south, is reversed when new ice is being formed near the coast of Antarctica in winter. Such a movement in winter towards the south may account for some of the fall of silicate as shown by the southern curve in September and October. However, such a southerly movement cannot be the sole reason for the fall in these months; later in this section another reason will be discussed. Unfortunately we have no averages for June and July, so that the extent of the fall in silicate content before 1 September cannot be known. The average values at 1 May and 1 September differ by over 800 mg., a difference which gives some indication of the extent of the fall of silicate content during the intervening months.

The rise in silicate content from 1 November is steep until 1 February, when it flattens during February and falls in March. The flattening in February and the fall in March may represent the effect of the peak concentration of phytoplankton production in situ for the southern region; if so, the effect of production in situ has only checked the rate of the rise of silicate content which started in November and has not been enough to override the increase, since in April the curve is again rising. The rise of silicate over the months of November, December, January, February and April with the evidence of masking in February and March must be due to the arrival at the southern region of warm deep water with a high silicate content some time previous to 1 November; this warm deep water then transfers its high silicate content to the Antarctic surface water by mixing. The rise over all these months cannot be due alone to regeneration in situ because the rise starts in November when the concentration of phytoplankton in the southern region is small, and only in late February does the production come to a peak. The possibility that the warm deep water carries back to the Antarctic zone undissolved diatom skeletons which dissolve in the far south and become available to the surface layer in these months is remote, because the main belt of diatom ooze is found near the Antarctic convergence, and the northern region diatoms are most likely to be deposited there.

In the curve for the northern region a fall of silicate occurs from 1 September to 1 January, followed by a rise to 1 April and a fall to 1 May. Dr Hart informs me that in the northern region the figures of phytoplankton concentration show a very slight production in August, which increases by 100 per cent in September, by 300 per cent in October and by 13,500 per cent during November. Owing to the large amount of silicate present in the surface layer in the northern region before the main outburst, very little effect will be shown as a result of consumption by phytoplankton until November when the increase in the concentration of phytoplankton is enormous. The fall in the northern curve from 1 September to 1 November is therefore unrelated to phytoplankton requirements, and it is only after 1 November that a correlation is possible between the fall of silicate content and the increase of phytoplankton concentration.

In the northern region the phytoplankton is definitely on the wane by the end of December, when the zooplankton must be exerting a greater effect on the concentration of phytoplankton than any continued production. This is partially reflected in the rise of the silicate averages from 1 January to 1 April, i.e. when the phytoplankton production falls off (and it falls off very rapidly) the monthly averages of silicate content start to increase. This increase must be due to regeneration *in situ* and to the arrival from the south of the Antarctic zone of surface water containing a larger amount of silicate. In the far south the Antarctic surface layer has a much greater silicate content than in the northern region; owing to the northerly component in the movement of the surface water the northern region will be continuously refreshed by the arrival of water of high silicate content from the south. The effect of phytoplankton production in the far south and in the intermediate zone will, however, tend to reduce the silicate content of surface water arriving at the northern region. The silicate values in the northern region for the 0–100 m. layer never approach in any month the high values recorded in the southern region for December to May, and thus we must assume that the difference between the maximum values in the two regions represents the amount of silicate that is utilized by the phytoplankton during the passage of the surface water across the Antarctic zone. This difference is of the order of 1250 mg., and this amount can only be held by the phytoplankton or be lost to the surface layer by sinking of dead diatom skeletons.

In the northern region curve a fall of silicate is shown for the month of April. This fall may be due to two causes: (1) a small autumnal outburst of phytoplankton or (2) the arrival in the northern region of surface water which has experienced peak conditions of the southern phytoplankton concentration. There is some evidence, but not a great amount, for the first cause, as the catches of phytoplankton show a slight increase in the autumn. As regards the second cause there is no doubt that the activity of phytoplankton in the southern region must have an effect on the silicate content of the surface water, which during its passage northwards across the Antarctic zone has more and more nutrient salts withdrawn by intermediate zone activity.

If we consider both the southern and northern curves we find that minima exist as follows: northern region 1 January, and southern region 1 November. We know too that in the northern region in November the phytoplankton increases enormously in concentration. It is obvious that this large increase exerts a tremendous effect on the concentration of nutrient salts in situ, and it is reasonable to ascribe the minimum in the northern curve at the end of December to this cause. Longitudinal sections of salinity show that the Antarctic surface water has a strong northerly component of movement as it sinks at the Antarctic convergence into sub-Antarctic water. When vertical sections of silicate content are plotted, it is seen that silicate leaves the Antarctic zone in two ways; the first is in the Antarctic surface current, which sinks at the convergence and ultimately forms part of the Antarctic intermediate water, and the second, the major loss, is in the Antarctic bottom water. Unlike phosphate, which has a maximum concentration at about 38°–43° S in the South Atlantic Ocean for example, silicate is found in greatest quantity inside the Antarctic zone. The silicate that leaves the Antarctic in the surface current travels a long way north before it is returned in the upper layers of the warm deep water, whilst the silicate that travels northwards in the Antarctic bottom water begins to return in the lower layers of the warm deep water at a much higher latitude. In the northern region, as we have seen, a sudden and large concentration of phytoplankton is found in November, which diminishes rapidly during the second half of December. The water which leaves the Antarctic zone and eventually becomes part of the Antarctic intermediate current will thus have a silicate content which varies seasonally, i.e. after the main phytoplankton outburst the surface water contains less nutrient salts, whilst in winter the sinking Antarctic surface water has a high nutrient salt content. It might be argued that after the main outburst, silicate in the form of diatoms also leaves the Antarctic, and therefore the sum total of silicate leaving is the same at all seasons of the year. But this is not correct. Phytoplankton is consumed by zooplankton and mortality occurs from other causes. Consequently a rain of the silicate skeletons of diatoms takes place; this rain will vary in amount depending on the concentration of the plankton, so that a seasonal effect will be found in the sinking silicate particles. The Antarctic intermediate current will have a silicate content which depends on the time of the year when the Antarctic surface water sinks at the convergence. Also, during the rain of silicate skeletons from the surface layer some will pass into the south-going warm deep water and others will sink into the Antarctic bottom current to refresh this layer and to help form the diatom ooze. Re-solution of silicate must take place in all three currents, and since a silicate cycle prevails, the amount of this salt which returns to the Antarctic will vary in different months of the year. It is therefore permissible to argue that a minimum in the silicate content of the surface layer in the northern region at the end of December will be reflected in the silicate content in the southern region, which as we have seen has a minimum at 1 November. It has been stated earlier in this report that the minimum at the beginning of November in the southern curve bears no relation to the production of phytoplankton in situ, and it is thus possible that this minimum is a reflection of the northern region minimum at the end of December. In this connexion it is remarkable that a rise takes place in the southern curve during November, December, January, and February during which time the southern region phytoplankton is slowly and steadily coming to a maximum in the third week of February. If the minimum of 1 November in the curve of the southern region is a reflection of the minimum in the northern curve at the end of the previous December, then the rise in the silicate content in the southern region for the months of November, December, January and February should be related to the rise in the northern curve for January, February, March and April. If the two minima are thus correlated the conditions in the southern region depend on those occurring 10 months or possibly 1 year and 10 months before in the northern region. It is possible that this will give some basis for a speculation as to how long silicate takes to be returned to the Antarctic.

As a summary of our present knowledge of the silicate content of the surface layer in the Antarctic zone the following remarks may be of service. The silicate content of the 0–100 m. layer in two arbitrarily defined regions of the Antarctic zone when plotted as 2-monthly averages give interesting curves. The rises and falls of these two curves are partly at variance with known dates and effects of phytoplankton growth and decline in situ. It is suggested that because the amount of silicate which leaves the Antarctic zone exhibits a seasonal change, the return cycle of silicate will cause this seasonal change to be mirrored in the silicate content of the surface layer in the southern region. Also, the northern region averages reflect the past history of phytoplankton activity in the southern and intermediate regions.

SEASONAL VARIATION OF PHOSPHATE AT THE SURFACE

The averages of phosphate and silicate contents of the 0–100 m. layer in two arbitrarily chosen regions of the Antarctic zone have been presented in the form of curves of 2-monthly means which gave an insight into the seasonal variation of these nutrient salts in the surface layer at the extreme south and north of the zone. The following remarks are a summarized account of the surface values in different months of the year as far as our observations allow. It is difficult to make a concise summary because the main phytoplankton outburst varies in date and extent. There is also some evidence of a small autumnal increase of phytoplankton, even more unevenly distributed. The surface and 0–100 m. layer observations for special areas, where data are more numerous, will be given later.

The average surface phosphate content at the ice-edge in September is of the order of 125 mg., except north-east of the Ross Sea where a higher value of over 140 mg. was recorded in 1932. The northern limit of the Antarctic zone has an average of about 110 mg., again except north-east of the Ross Sea.

In October surface values at the ice-edge of about 110–115 mg. have been found, whilst northern boundary values of about 105 mg. are recorded.

In November ice-edge surface values are about 105–110 mg. whilst northern boundary figures vary between 70 and 90 mg., the value depending entirely on the date of the main outburst of phytoplankton.

In late December ice-edge values of 95–100 mg. have been found, whilst just south of the Antarctic convergence an average surface value of 75–80 mg. is usual.

In January the ice-edge surface content is of the order of 85–90 mg. with northern boundary values of 75–80 mg., although north of the Ross Sea in mid-January 1934 surface contents of 61 and 59 mg. were recorded at 67° 33·8′ S and 62° 08·1′ S respectively. These low values were separated by a content of 112 mg. at 65° 05·3′ S.

For February an average ice-edge value of the order of 80–85 mg. is found, whilst the northern boundary value approximates to 75 mg.

In March ice-edge surface values are of the order 90–100 mg., but individual stations give results which vary considerably. At the northern boundary of the Antarctic zone the surface content is about 100 mg.

The available April ice-edge values show that the position at the far south is complicated either by very late phytoplankton outbursts or else secondary autumnal concentrations. At the end of April 1932 at the ice-edge north of Enderby Land the surface value was 87 mg., whilst close to the South Orkneys in early April 1934 the value was 79 mg. On the other hand, the surface content steadily increased southwards in early May 1934 towards the ice-edge north of Enderby Land, where a value of 130 mg. was recorded. Northern boundary values are of the order of 100 mg. in April.

In May at the few ice-edge stations the surface value is 130 mg. with northern boundary figures of 115–120 mg.

There are insufficient observations in June, July and August to offer any average values, but it is of interest to note that on an average date of 30 August 1934, twelve stations around South Georgia gave an average surface content of 120 mg.

SEASONAL VARIATION OF SILICATE AT THE SURFACE

The following is a brief summary of our current knowledge of the silicate content in different months. Silicate analyses were made a routine only during the third commission of R.R.S. 'Discovery II', and therefore we cannot yet discuss the seasonal silicate content all over the Southern Ocean. In certain areas such as the Pacific ice-edge, 80° W, Scotia Sea and South Georgia observations were made in several months.

In September the data are confined to parts of the South Pacific Ocean and between the Falkland Islands and Elephant Island. Those for the South Pacific agree with one of the main conclusions drawn from the December–January and February–March ice-edge cruises; this conclusion was that the silicate content in the ice-edge region of the south Pacific is greater in the west than in the east. Thus in the second week of September 1932 at the ice-edge north of the Ross Sea two surface observations were of the order 2000–2500 mg., whilst in late September 1932 a value of only 1000 mg. was found at a position not far from the ice-edge in 98° W, a figure supported by another observation in 80° W of 1150 mg. at the ice-edge in the second week of September 1934. At the northern boundary of the zone in the South Pacific the available figures vary from 800 to 1400 mg. in the west and from 850 to 1150 mg. in the eastern part. In late September 1934 the stations in the Antarctic zone between the Falkland Islands and Elephant Island had a surface silicate content of 900 mg. in the north and of 1400 mg. in the south.

In October the data are still very meagre; between South Georgia and the Falklands the surface silicate content in the Antarctic zone in the second week of October 1934 varied from about 1050 mg. in the east to 750 mg. in the west, whilst a few days earlier a value of 1250 mg. was obtained some 180 miles north of the South Orkneys. In 80° W the ice-edge had retreated at the end of October 1934 some 140 miles from the position in the second week of September, to a latitude where the silicate content at the surface was 2000 mg. in place of 1150 mg. in September. The northern boundary of the zone in 80° W had a surface value of 1150 mg., the same as it September.

In early November 1934 some fourteen stations between $59\frac{1}{2}°$–$66\frac{1}{2}°$ S and 80°–110° W gave an average surface value of 1250 mg., whilst those actually at the ice-edge had an average content of 1575 mg. A few days later in 80° W the ice-edge surface content was 1475 mg., and at the northern boundary 1050 mg. was recorded. At a number of stations near South Georgia at the end of November 1933 the average surface figure was 650 mg. at a time when enormous catches of phytoplankton were being made, so that peak conditions for the withdrawal of silicate from the surface layer were prevailing. Owing to upwelling and turbulent mixing in the vicinity of South Georgia it is likely that the photosynthetic layer around the island will always have more silicate present than in the open ocean at the same distance from the Antarctic convergence. This follows from the results of the survey at South Georgia in November 1933 when even with the enormous concentrations of phytoplankton present, probably the heaviest in the world, there was still an average of over 650 mg. remaining in the surface (see footnote p. 112). At St. 1198, which was situated close to the northern boundary of the Antarctic Zone and was made immediately previous to the November 1933 survey at South Georgia, the surface value was 0 mg.; a heavy concentration of phytoplankton was present. This would seem to indicate that at the time of the peak concentrations of phytoplankton the silicate content of the surface may be reduced to zero, and that if it were not for upwelling and turbulent mixing at South Georgia the silicate content around the island might be completely utilized in the photosynthetic layer. The actual concentration of phytoplankton around South Georgia in November 1933 was more than $1\frac{1}{2}$ times greater than at St. 1198.

In December our data are confined to parts of the Scotia Sea and to 80° W. In December 1933 the surface content 60–70 miles north-east of South Georgia was 500 mg.; this value increased to the south-west of the island. North-east of South Georgia a very heavy toll had been taken by the phytoplankton. South-west of the island the observations were made at places close to the line of pack-ice which is usually present in the early part of the season near the Shetland-Orkney ridge, and the surface value here was over 2000 mg., whilst at the ice-edge in 80° W a value of 2100 mg. was found. In late December 1933, in the Antarctic zone between the Falklands and the ice-edge in 77° W, the surface value increased from 450 mg. in the north to 1950 mg. at the ice-edge. In December 1933 the value decreased towards the north in 80° W from a value 2100 mg. at the ice-edge to 900 mg. at the northern boundary of the zone.

In January 1934 the average ice-edge value across the South Pacific was 2050 mg., and the average of all stations within 250 miles of the ice-edge was 1700 mg. The ice-edge content in the extreme east was of the order of 2000 mg. and between 86° and 109° W it fell below 1000 mg.; west of 109° W it increased again to over 2000 mg. The position in which the surface content fell below 1000 mg. appears to be related to a bending of the surface current towards the south.[1] In late January 1934 a line of observations from the eastern entrance to the Ross Sea in 69¾° S, 159¼° W towards New Zealand showed that at the southern end the surface content was 2600 mg., a value which increased to 3200 mg. in 65° 05′ S, 166° 08′ W. This value was the only example in the South Pacific of a surface content of such a high order. North of this extremely high value the content fell rapidly, so that at St. 1273 in 62° 08·1′ S, 169° 59·9′ W there were less than 200 mg. of silicate in the surface. It may be added that the position of St. 1273 is well south of the Antarctic convergence, and the great disparity between the surface content at this position and that found a short distance farther south shows very clearly how the concentration of a nutrient salt can vary very considerably over a short distance in the Antarctic zone.

In late January 1935 the silicate contents at stations in the Scotia Sea showed that phytoplankton had reduced the amount present. Thus the surface content near the South Orkney Islands was only 650 mg., and this value diminished northwards so that just south of the Antarctic convergence less than 300 mg. were present.

In a survey around South Georgia with an average date of 3 February 1935, the average surface value was 750 mg., whereas we have seen that in the previous week the Scotia Sea content was 650 mg. near the South Orkneys, and less than 300 mg. in the north. A comparison of these figures suggests that there is always more silicate available around South Georgia than in the open sea.

In mid-February 1935 the average silicate content found in the surface during a cruise from a position just south of the South Sandwich Islands to the ice-edge at the eastern entrance to the Weddell Sea and along the ice-edge to 42½° E, was 2650 mg. for eighteen stations; the content at the ice-edge averaged 2950 mg. The average contents were lowered by the values at some stations with large phytoplankton concentrations and by those of a "grazed down" area east of 30° E. Probable ice-edge figures for the South Atlantic are of the order 3000–3500 mg. before the main phytoplankton outburst.

In early March 1935 at 42½° E the ice-edge surface value was 2700 mg., a value which decreased towards the north until just south of the Antarctic convergence the content was 1000 mg. In mid-March 1933 the ice-edge value was 2700 mg. at 69° 30′ S, 9° 34′ E, and this also decreased towards the north to 2000 mg. some 250 miles south of the convergence.

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[1] Deacon, 1937, p. 38.

In late March 1934 the western part of the Scotia Sea had a surface content of 1500 mg. which decreased to 850 mg. at the northern boundary of the Antarctic zone.

In the South Pacific Ocean in March 1934 fifteen stations within 250 miles of the ice-edge gave an average value of 1550 mg., with an average of 1750 mg. at the actual ice-edge. A smaller silicate content was again found between 86° and 110° W. At 80° W in March 1934 the surface value dropped from 1750 mg. at the ice-edge to less than 300 mg. at the Antarctic convergence.

In early April 1934 the surface content in the middle of the Scotia Sea varied from 3050 mg. close to the South Orkney Islands to 350 mg. just south of the convergence. In late April 1934, outside the Scotia Sea, some observations made just east of the South Sandwich Islands showed that the surface silicate slowly increased southwards from less than 300 to 1100 mg. and then jumped to 3050 mg. at the most southerly station in 61° 19·5′ S, 21° 39·1′ W. This line of observations was interesting because the surface water at all stations except the most southerly had passed through the Scotia Sea and across the ridge between South Georgia and the South Sandwich Islands, losing silicate by phytoplankton activity in the crossing. The high content at the most southerly station was due to the station being made in Weddell Sea water which has a very high silicate content. The surface content of 3050 mg. corresponded exactly with that measured a few days earlier close to the South Orkneys.

In mid-April 1932 in the Antarctic zone between the longitude of Cape Town and Enderby Land the surface silicate increased southwards from 2400 to 3400 mg. at the ice-edge.

In May 1934 between 58½° S, 16° E and the ice-edge in 45° E, the surface silicate fell southwards from 2700 mg. to the order of 1500–2000 mg. and then increased to about 2000–2500 mg. near the ice-edge. The fact that the content fell to a value of 1500–2000 mg. was probably due to a large concentration of phytoplankton having consumed the nutrient salts previous to the time of our observations. It will be remembered that in February 1935 we came upon strong evidence for a large concentration of phytoplankton near this position. Between the ice-edge in 45° E and the region just south of the Antarctic convergence near the Crozets, in May 1934, the surface content fell from 2200 to 850 mg.

In late May 1932, south of Australia, the silicate content in the Antarctic zone increased southwards from a value of 450 to 2700 mg. at the ice-edge north of Adélie Land.

There are no observations for June and July, but in late August 1934 the surface value at 55° S, 20° W was 2050 mg., a value which decreased towards the north-west until just south of the convergence it was 1150 mg. Around South Georgia, which is about 250 miles south of the convergence, an average value at twelve stations in late August 1934 was 1750 mg.

SEASONAL VARIATION OF PHOSPHATE IN THE SURFACE LAYER AROUND SOUTH GEORGIA

Although samples for phosphate analysis were taken in the hydrological surveys of December 1926–January 1927, August–September 1928 and December 1928–January 1929, it is not considered that an accurate account of the seasonal variation of phosphate in the surface layer at South Georgia can be obtained from a study of these figures. The objection is that these results were obtained from samples which had been stored for varying amounts of time before analysis, and the results are therefore liable to be affected by phyloplankton and bacteria. We are therefore left with five sets of observations on which analysis was made immediately the samples had attained laboratory temperature. The average dates of these observations, the average contents for the surface and 0–100 m. layer are given in Table IV.

Table IV

Stations	No. of observations	Average date	Average phosphate mg./m.^{3}	
			Surface	0–100 m.
300– 358	57	1. ii. 1930	79	82
475– 525	49	21. xi. 1930	84	89
1199–1211	12	30. xi. 1933	108	109
1394–1406	12	30. viii. 1934	120	122
1496–1508	12	3. ii. 1935	74	82

Unfortunately, in addition to the material being collected in different years, only three months are represented, and although these are such that they represent an approach to maximum and minimum amounts of phosphate content, no complete graph of the seasonal variation can be drawn. It is interesting to note that the 0–100 m. averages are nearly the same as the surface values in all the sets of observations. This is an indication of the thorough mixing to which the surface layer is subjected at South Georgia. The average surface value of 120 mg. at the end of August 1934 must be very close to the maximum content in this vicinity.

The February observations were taken at times which were well past those of the peak concentrations of phytoplankton, and thus the two surface averages in 1930 and 1935 of 79 and 74 mg. respectively, are probably higher than the average for December, i.e. just after the maximum concentration is reached. In 1930 and 1935 the averages for the 0–100 m. layer had the same value. Exceptionally, the surface value has fallen to figures of 53 and 40 mg.[1] in early February, but it is obvious that a more usual value is of the order of 75–80 mg. This would seem to indicate that the average minimum surface value around South Georgia in late December or early January is probably of the order 65–70 mg., as opposed to a mid-winter figure of about 120–130 mg., the maximum surface content recorded in August 1934 being 130 mg. If the order of magnitude of these values is correct, phosphate is withdrawn at South Georgia by the plankton to an extent of about 45 per cent of the available content in the surface. The amount withdrawn from the 0–100 m. layer is a little less.

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[1] See also footnote on p. 112.

At Grytviken, South Georgia, during part of 1925–6, a daily surface sample was taken at high tide and analysed for phosphate content. Although such factors as dilution by land drainage, snow water, glacier ice, and varying contamination during the whaling season diminished the value of these estimations, it is considered that the results furnish some indications of the seasonal variation of surface phosphate at one position at South Georgia. The results were plotted as monthly means and are given in graphical form in Fig. 10.

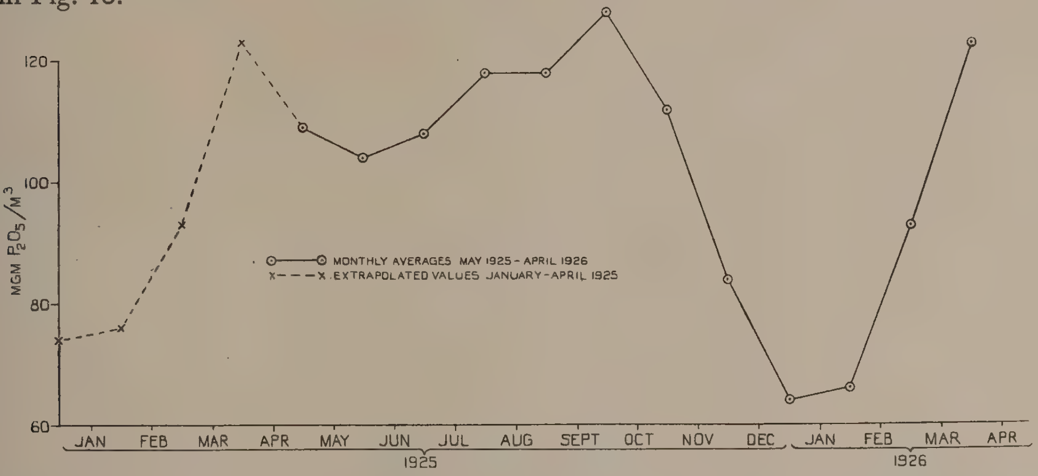

Fig. 10. Monthly averages of phosphate content in the surface water at Grytviken, South Georgia in 1925–6.

The two surveys of November 1930 and 1933 (Table IV) give an indication of the annual variation of phosphate in the surface layer. If we attempt to compare these November results by reducing the number of stations made in 1930 so that the positions of the stations in the 2 years are more nearly comparable, we find that twenty-three stations in 1930 give an average of 92 mg. for the 0–100 m. layer compared with an average of 109 for twelve stations in 1933. Possible factors which might be responsible for the difference of 17 mg. in these 2 years are difference of average date of the stations involved, meteorological differences, amount of phytoplankton and date of main outburst in each year, and hydrological differences in the surface layers. The average date the twenty-three stations taken in 1930 which correspond with the positions of the twelve stations of 1933, was 17 November as opposed to 30 November in 1933. In the absence of exact information as to the dates of the main outburst in the 2 years, the fact that the average date of the survey in 1930 was 13 days earlier than in 1933 would tend to argue that the phosphate content of the surface layer should have been greater in 1930 than in 1933 because the phosphate content decreases towards the summer. Thus the factor due to the difference of date of the two surveys should have given rise to more phosphate being removed in 1933 by phytoplankton activities, whereas the surface layer was found to contain more phosphate in 1933 than in 1930. In the opinion of Dr Hart the 1933 survey was made immediately after peak conditions of phytoplankton concentration, whilst the comparable stations in 1930 were made at the beginning of the upward gradient of phytoplankton growth. Phytoplankton requirements therefore would have removed less phosphate at the time of the survey in 1930 than in 1933, i.e. the residual phosphate should have been greater in 1930 than in 1933.

The average wind velocity for the dates of the 1930 stations was 18 knots, and for those in 1933 was 12 knots; similarly, the sky was clearer during the 1933 observations than during those of 1930. In general, clear, calm conditions favour phytoplankton growth, and therefore the fact that the survey of 1930 was made in more overcast weather and at a time when more turbulence was apparent than in 1933 would tend to favour a greater phytoplankton concentration in 1933 than in 1930; this would involve a smaller residual phosphate content in the surface layer in 1933, which is exactly opposite to what was found. Hydrological conditions were very different in November 1930 from those in 1933. In November 1930 vast masses of heavy pack-ice were close to the northern coast of South Georgia, whilst there was no pack-ice visible at the time of the 1933 survey. The presence of pack-ice around South Georgia in early spring is due to a current from the Weddell Sea. Although we have no figures at present for the transport of water out of the Weddell Sea, it is possible that in a year when large masses of ice are found at South Georgia, the Weddell Sea influence predominates over that of the Bellingshausen Sea which is the second source of surface water in this vicinity. At South Georgia, water of Weddell Sea origin appears in spring to have a higher phosphate content than that of Bellingshausen Sea origin. Thus if a greater amount of Weddell water were present in 1930 it would again have been expected that more phosphate would have been present in 1930 than in 1933. The presence of such a large quantity of pack-ice in 1930 lowered the average temperature of the surface layer. The average temperature of the 0–100 m. layer in the two Novembers was as follows:

November 1930, 49 stations, −0·67° C.
November 1930, 23 stations, −0·68° C.
November 1933, 12 stations, 0·50° C.

Thus even if all the stations of 1930 or only those comparable in position with the 1933 stations are considered there is a difference of nearly 1·20° C. in the mean integral average of the 0–100 m. layer in the 2 years. It is not known whether phytoplankton has an optimum temperature for the beginning and duration of the period of increase in concentration. It is possible, however, that such a relatively large difference in temperature of the surface layer in these 2 years is likely to have had a significance, the import of which is at present unknown.

The above evidence therefore does not explain the presence of more phosphate in the surface layer around South Georgia in November 1933 than there was in the same month of 1930. It is clear that the phosphate content of the surface layer varies very considerably from year to year, and the difference between the results of 1930 and 1933 must be due to some annual variation. Until we have much more data, any further discussion on this point must be postponed.

SEASONAL VARIATION OF SILICATE IN THE SURFACE LAYER AROUND SOUTH GEORGIA

At present there are insufficient data for a complete examination of the seasonal variation of silicate in the surface layer at South Georgia. There are observations in December 1932 (twelve stations), February 1933 (four stations), November 1933 (twelve stations), August 1934 (twelve stations) and February 1935 (twelve stations), but no data from the critical months of October, January, April and May. The importance of securing data from these months is that the steepness of the fall of silicate content in early spring is hidden by the absence of October values; the probable position of the minimal value close to 1 January also cannot be shown, and any evidence for an autumnal secondary outburst of phytoplankton is missing. The available figures have, however, been graphed and are shown in Fig. 11 as possible curves for the average contents of the surface and 0–100 m. layer between late August and mid-February. The figures in parenthesis opposite the points on the curves refer to the number of observations available.

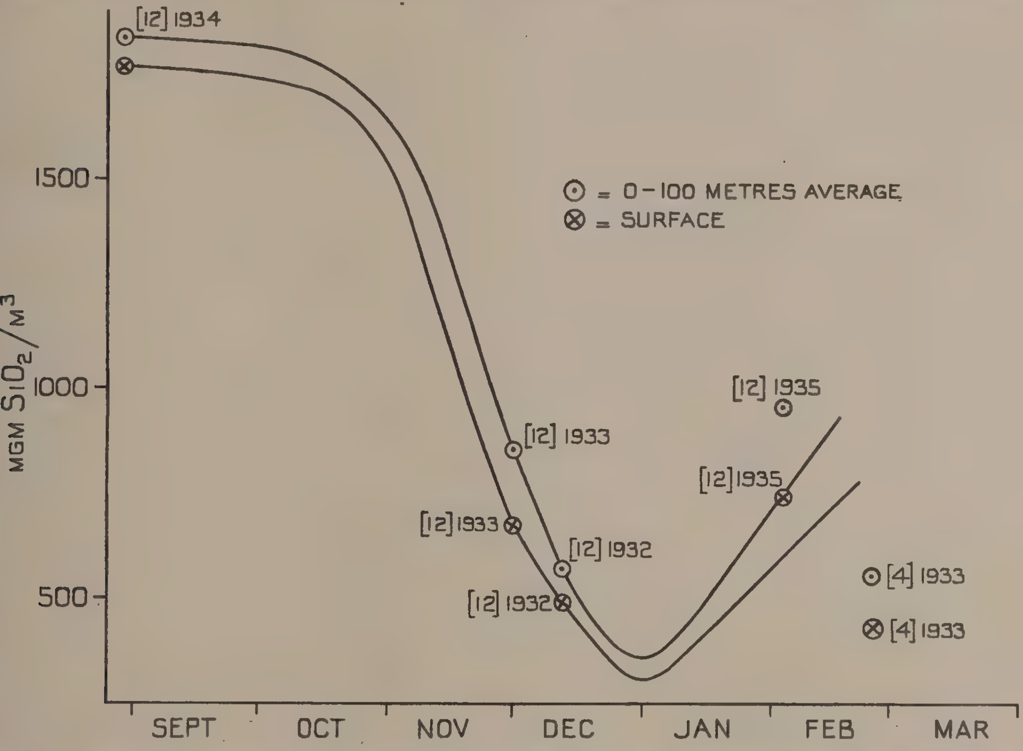

Fig. 11. Possible curves for the seasonal variation in silicate content of the surface and of the average of the 0–100 m. layer at South Georgia.

As may be seen, the average value of the 0–100 m. layer falls slowly from a value of about 1850 mg. at the end of August until about 1 November, when the gradient becomes much steeper and the silicate content falls to a probable minimal value of less than about 400 mg. near 1 January. Regeneration must be fairly rapid because in late February 1933 the 0–100 m. content was 550 mg., and in early February 1935 as much as 950 mg.

was present. If the proposed values for the maximal and minimal contents around South Georgia are correct then the net withdrawal of silicate in the 0–100 m. layer is about 81 per cent of the available silicate (see, however, footnote on p. 112). The surface withdrawal is most certainly of the same high order.

SEASONAL VARIATION OF PHOSPHATE IN THE SURFACE LAYER IN THE SCOTIA SEA

The Scotia Sea is bounded by the rise of the sea bottom in the arc extending from the Burdwood Bank towards the Shag Rocks and South Georgia and continued through the South Sandwich Islands, bending back to the South Orkney and Shetland Islands. We have seasonal data from two main lines of stations running northwards across the sea, one from Elephant Island to the Falklands and the other northwards from the South Orkney Islands across the Antarctic convergence. In addition we have data from a line of stations (Sts. 633–638) midway between the other two lines. It was considered that the few stations on these lines which lie north of the Scotia arc should also be included in this discussion owing to the common origin of the water at these stations and those in the Scotia Sea proper.

The surface and 0–100 m. layer averages have been plotted for these lines of stations, and are shown in Figs. 12, 13. For the stations northwards from the South Orkney Islands Fig. 13 shows a very uniform phosphate content from south to north in the months of October and January at the surface and in the 0–100 m. layer. In January the Antarctic surface water is universally low in phosphate content and the curves show the effect of the main phytoplankton outburst. The surface value is as low as 71 mg. and varies between 71 and 79 mg. in the Antarctic zone. In October the phosphate content is again uniform across the sea and represents the conditions before the main phytoplankton outburst which occurs a short time later. The phosphate content in October is of the order of 110 mg. at the surface and is not very much greater in the 0–100 m. layer, a fact which shows the effect of winter mixing. The October values are probably not maximal, and in the absence of July or August figures we can only say that the net amount of phosphate which is withdrawn from the surface by the phytoplankton during the spring and summer season is at least 36 mg.

The April curves for the stations north of the South Orkney Islands and the March curves for the line a few degrees to the west are interesting in their lack of uniformity when compared with those of January and October. The phosphate content at any position is merely the reflection of some past concentration of phytoplankton and of regeneration or return of this salt. In April the curves for both the surface and the 0–100 m. layer show wide variation, the surface value varying between the low values found in January and the high contents of October. Regeneration must be proceeding in April, but the effect of regeneration may be masked by changes in movements of the surface water, by localized autumnal secondary outbursts and by the arrival of water which has experienced peak conditions farther south and is now low

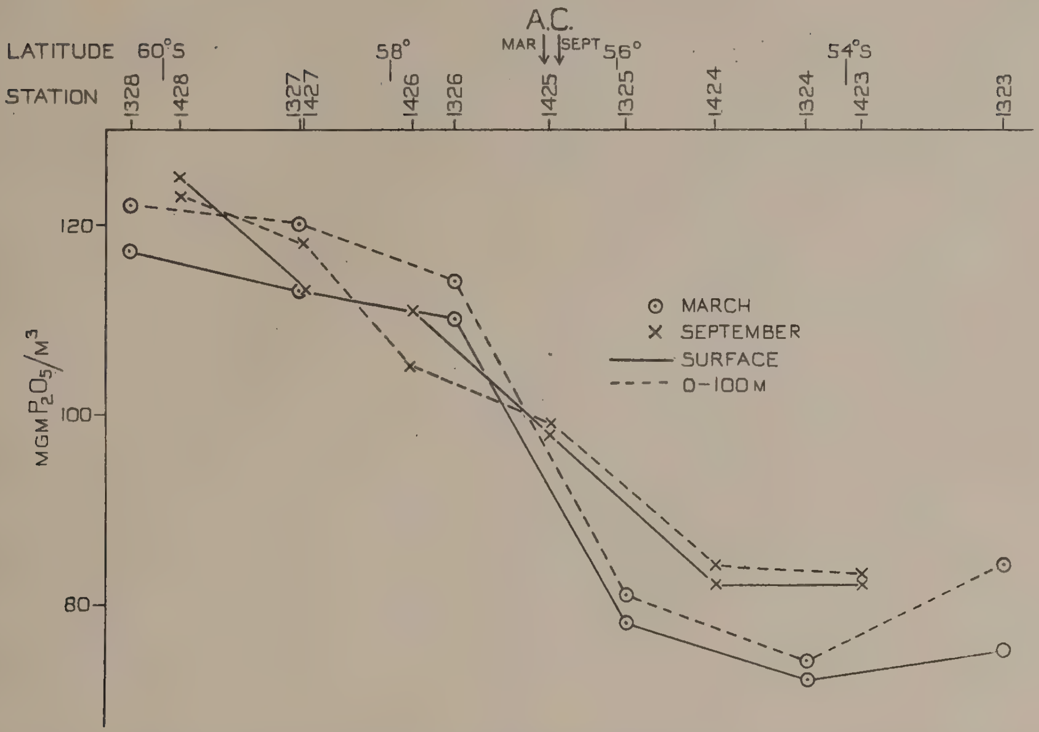

Fig. 12. Surface phosphate content and the average phosphate content of the 0–100 m. layer between the Falkland Islands and Elephant Island.

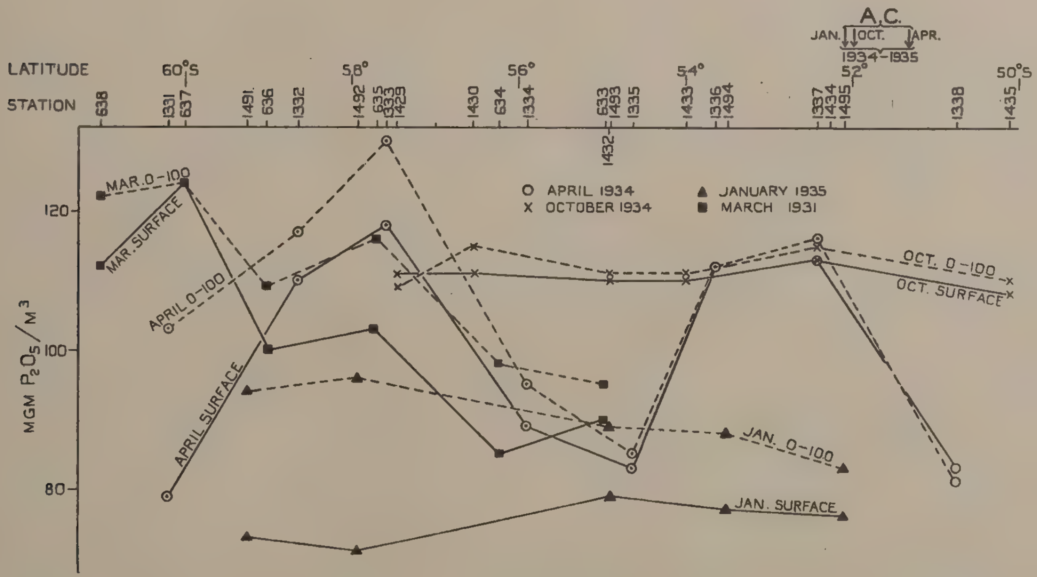

Fig. 13. Surface phosphate content and the average phosphate content of the 0–100 m. layer from the South Orkney Islands northwards to the Antarctic convergence.

in phosphate. The concentrations of phytoplankton actually found on this line of stations in April do not justify the term autumnal outburst, and it seems safer to assign the reason for the varied phosphate content in this month to a combination of other causes. The surface water in the Scotia Sea is composed of water which has passed through the Drake Passage from the Bellingshausen Sea and of water from the Weddell Sea. There is a difference in the concentration of phytoplankton supported by the Bellingshausen and Weddell Sea waters, and a corresponding difference at the end of summer in the phosphate content remaining in these waters. North of the South Orkneys the isotherms show that the Weddell sea water makes a series of thrusts among the water of Bellingshausen Sea origin, with the result, at this time of the year, of a varied phosphate content in the surface layer. Any phytoplankton activity in the far south of the Weddell Sea will have repercussions in the phosphate content of the water arriving at the South Orkney Islands. The January observations are uniform because they were made at a time too early for them to show any effect of heavy withdrawal of nutrient salt in the far south, and they merely reflect the uniform withdrawal in the Scotia Sea, i.e. in situ. The main outburst farther south does not reach its maximum until late in February, and water arriving at the southern end of our series of stations in March or April will show the effect of the peak production farther south superimposed on any regeneration occurring in situ. It is interesting to note that the surface phosphate content at St. 1331, the most southerly station and the closest to the South Orkney Islands, is the lowest of all the observations in April, whereas the silicate content at this station is the highest among these observations. This difference in magnitude of nutrient salt content must be connected with a difference in speed of regeneration of phosphate and silicate.

Between the Falkland Islands and Elephant Island there are two sets of observations, one in March and the other in September, both taken immediately before the April and October data north of the South Orkneys. Owing to the north-easterly trend of the Antarctic convergence there are fewer stations in the Antarctic zone between the Falklands and Elephant Island than north of the South Orkneys. The surface content and average of the 0–100 m. layer are plotted in Fig. 12 for both the Antarctic and sub-Antarctic zone stations. The absence of any zigzag effect in the March curves is striking; this is in contrast with the curves for the observations to the east, i.e. northward of the South Orkney Islands which were taken in early April within a day or two of the observations south of the Falklands. The uniformity may be due to the fact that the observations in the Antarctic zone south of the Falklands were made in water mainly of Bellingshausen Sea origin, whereas the observations north of the South Orkney Islands are subject to the influence of the Weddell Sea. The phytoplankton concentrations in the Bellingshausen Sea are smaller than those in the Weddell Sea; thus any effective removal of nutrient salt in the Weddell Sea will have a much greater effect on the nutrient salt content of the water near the South Orkneys than the effect of phytoplankton activity in the Bellingshausen Sea will have on the surface layer at the south end of the line of stations from the Falklands. The surface values of phosphate content at corresponding stations on the two lines, Sts. 1328 and 1331, for example, are respectively 117 and 79 mg. This difference of phosphate values must be due to earlier differences in concentration of phytoplankton in the far south of each line of stations. It cannot be said that the phosphate content disparity is due to differences of concentration of phytoplankton in situ because at both stations the phytoplankton catches in late March and early April were negligible. Nevertheless I think that there had been some influence of Weddell Sea water in the surface layer at St. 1328, the most southerly station south of the Falklands, because the mean value of the 0–100 m. layer silicate content was so much greater than that of the stations north of it.

The absence of December or January observations prevents any estimation of the net withdrawal of phosphate in these observations.

SEASONAL VARIATION OF SILICATE IN THE SURFACE LAYER IN THE SCOTIA SEA

The available data are restricted to a line of stations between South Georgia and the Falklands, three sets of observations from the South Orkney Islands northwards to the Antarctic convergence, and two lines of stations between the Falklands and Elephant Island.

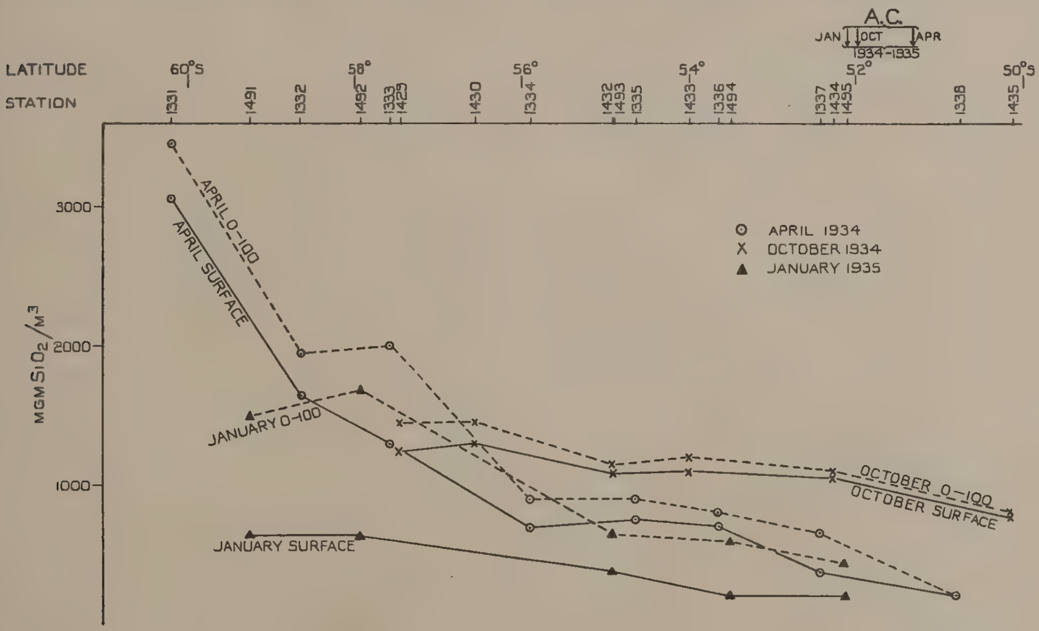

Fig. 14. Surface silicate content and the average silicate content of the 0–100 m. layer from the South Orkney Islands northwards to the Antarctic convergence.

Between South Georgia and the Falkland Islands in October 1934 the surface value of silicate content was of the order 1000 mg. in the Antarctic zone. North of the South Orkneys the observations were made in January, April and October and are shown in graphical form in Fig. 14. As with the phosphate distribution, the silicate content in the surface and the 0–100 m. layer shows very little variation from south to north across the Scotia Sea in the months of January and October. The April observations fall midway between those of January and October, showing that regeneration is having an effect in the increased value of the April figures over those of January. The April values for silicate content are more uniform than those for phosphate, and, except close to the South Orkney Islands, the silicate content falls gently from south to north. The reason for this may lie in the quicker regeneration in situ of silicate over phosphate, which latter is partly held by the zooplankton, whereas a large proportion of the silica skeleton of the diatoms is excreted when the phytoplankton is consumed by the zooplankton. The high value at the most southerly station in April is due to the presence of Weddell Sea water close to the South Orkney Islands. The January values probably approach very closely to the minimum concentration of silicate in the surface layer of the Scotia Sea, and, in the absence of observations earlier than October, we can say that a minimum of about 50 per cent of the available silicate is withdrawn during the phytoplankton season at the south of the Scotia Sea, and something approaching 80 per cent in the north.

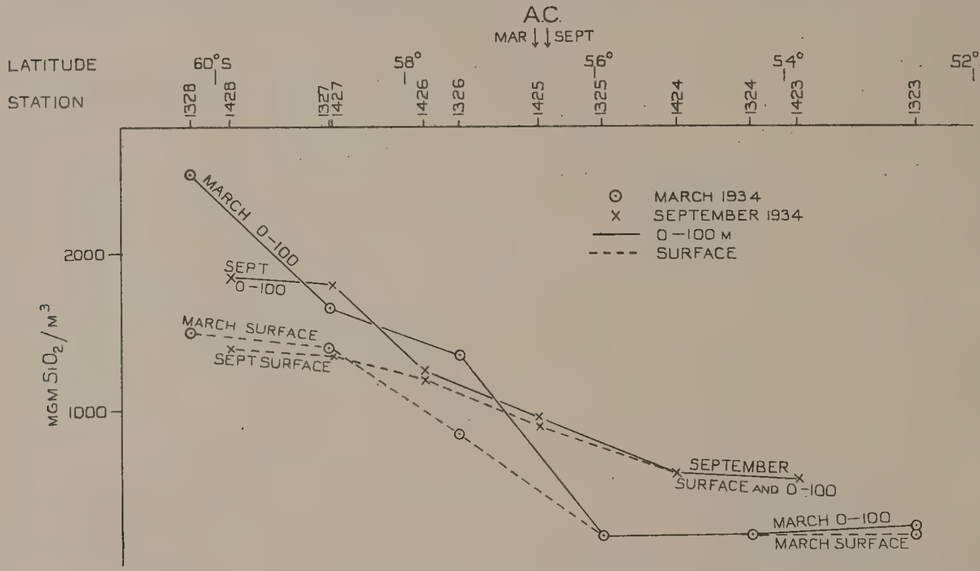

Fig. 15. Surface silicate content and the average silicate content of the 0–100 m. layer between the Falkland Islands and Elephant Island.

Between the Falkland Islands and Elephant Island there are only two sets of data, one obtained in March 1934 and the other in September 1934, each set of observations having been made immediately previous to those in April and October north of the South Orkneys. They are shown in graphical form in Fig. 15. Considerably less silicate exists in the west of the Scotia Sea than north of the South Orkneys. In general the September values are greater than the March ones and must approach the maximum values in this position during the year. Considerably more data are required on this line of stations before seasonal variation in the western part of the Scotia Sea can be discussed.

SEASONAL VARIATION OF PHOSPHATE IN THE SURFACE LAYER IN 80° W

In 80° W a series of observations for phosphate and silicate analysis were made in five months in 1933–4, since the phosphate results of December 1933 were found to be inaccurate only those taken in 1934 have been examined. The mean integral averages of the 0–100 m. layer have been plotted and are shown in Fig. 16. Discussion of these averages is handicapped by variation of the latitude of the ice-edge and of the Antarctic convergence, and the narrowing of the Antarctic zone in 80° W due to geographical features. The ice-edge in March 1934 was some 280 miles farther south than in September 1934, and the Antarctic convergence was over 60 miles farther south in March than in September. In September and October the concentration of phytoplankton in the Antarctic surface water was very small, and even in November the main outburst had hardly started; the March observations were made after the peak concentration of phytoplankton in the far south.

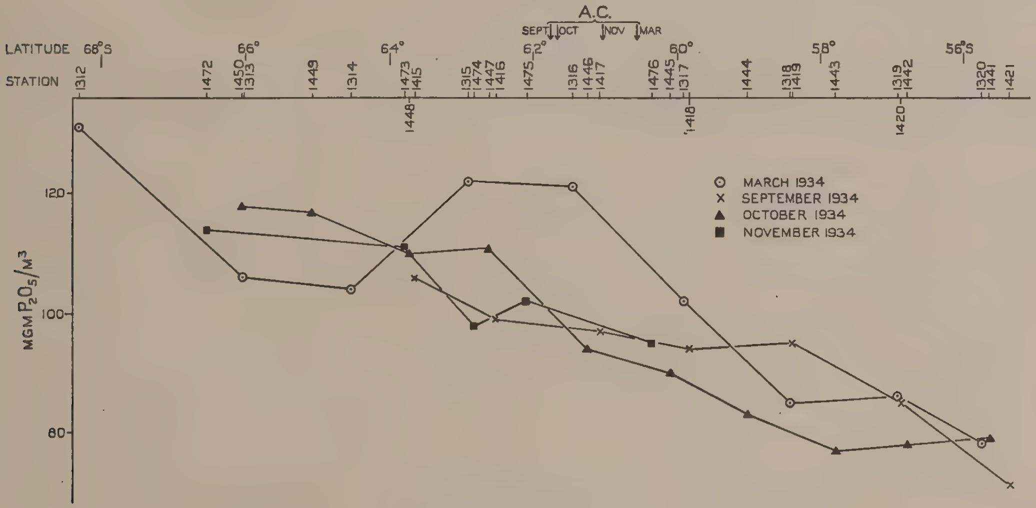

Fig. 16. The average phosphate content of the 0–100 m. layer in 80° W.

At the Antarctic convergence in 80° W very little variation of phosphate content occurred in the 0–100 m. layer in the months of September, October and November, whilst farther south, October averages were higher than in November. We have no results for the critical period of early January to late February which would show the effect of the peak concentrations near the convergence and at the ice-edge, and hence only a very approximate estimate of the consumption of phosphate can be made. The March observations were interesting because in the far south they show some effect of the peak concentration of phytoplankton which must have been present some little time previously. North of 64½° S, however, the March averages are seen to rise and attain the highest values recorded for any month in corresponding latitude, as far as about 59° S. This is at a time after peak conditions of phytoplankton concentration in the far south, and well after the maximum concentration at the convergence. The increase of phosphate must be due to regeneration, but as the salinity and temperature results between 0 and 60 m. at Sts. 1315 and 1316 show, it was due to regeneration in sub-Antarctic surface water which had passed over the Antarctic convergence. In the south of the sub-Antarctic zone the main outburst of phytoplankton occurs earlier than south of the convergence; regeneration will set in earlier too, so that the effect of a withdrawal of phosphate at the ice-edge in February was masked in the region between 64½° and 59° S by the presence in the 0–60 m. layer of sub-Antarctic surface water which was showing a high degree of regeneration. If we assume that at approximately 66° S the phosphate content in February 1934 was lower than in March of the same year and that the mean integral average of the 0–100 m. layer in February was about 100 mg., then a minimum withdrawal of about 20 mg. would occur in this layer during the phytoplankton season in this latitude. At the Antarctic convergence no estimate of the consumption of phosphate can be given owing to the absence of observations unaffected by sub-Antarctic water.

SEASONAL VARIATION OF SILICATE IN THE SURFACE LAYER IN 80° W

The mean integral averages of the 0–100 m. layer have been calculated and are plotted in Fig. 17. North of about 63½° S only a very small variation in silicate content of this layer was found in September, October, November and December. In 1934 the September, October and November observations just south of the convergence were made within a period of 64 days, during which time the increase in concentration of phytoplankton in this position was very small. This lack of variation in the silicate content of the surface layer during these months also reflects the paucity of the concentration of phytoplankton.

The silicate values in March 1934 were everywhere lower than in any other month, and the curve in Fig. 17 for this month does not show the peaks which are such a conspicuous feature of the phosphate curve. This is because the silicate content of sub-Antarctic surface water is considerably lower than that of Antarctic surface water, and the ratio of phosphate to silicate in the Antarctic water is much smaller than in sub-Antarctic water. Hence the presence of sub-Antarctic water in the 0–60 m. layer at Sts. 1315 and 1316, which is showing a high degree of regeneration of phosphate, will not cause corresponding peaks in the silicate curve for these stations.

In all months a fall of silicate occurs northwards from the ice-edge as far north as about 62½°–63½° S, where a horizontal portion is found in all the curves. There is no counterpart of this horizontal portion in the phosphate curves except in October; the existence of this horizontal part of the curves is not dependent on phytoplankton activity alone, because it occurs both in September and October when the concentration of phytoplankton is extremely small and in November and December when the amount of phytoplankton is increasing.

The curves show that there was a rapid decrease of silicate in the 0–100 m. layer from the ice-edge to far north as 63½° S in all the months examined. In March this rapid fall was of the order of 1850 mg. and in the other months 550–1200 mg. In March the extent of the fall is exaggerated by the presence of sub-Antarctic water of low silicate content in the 0–60 m. layer at Sts. 1315 and 1316. When the narrow width of the Antarctic zone in 80° W is considered the silicate gradient across the zone is very steep.

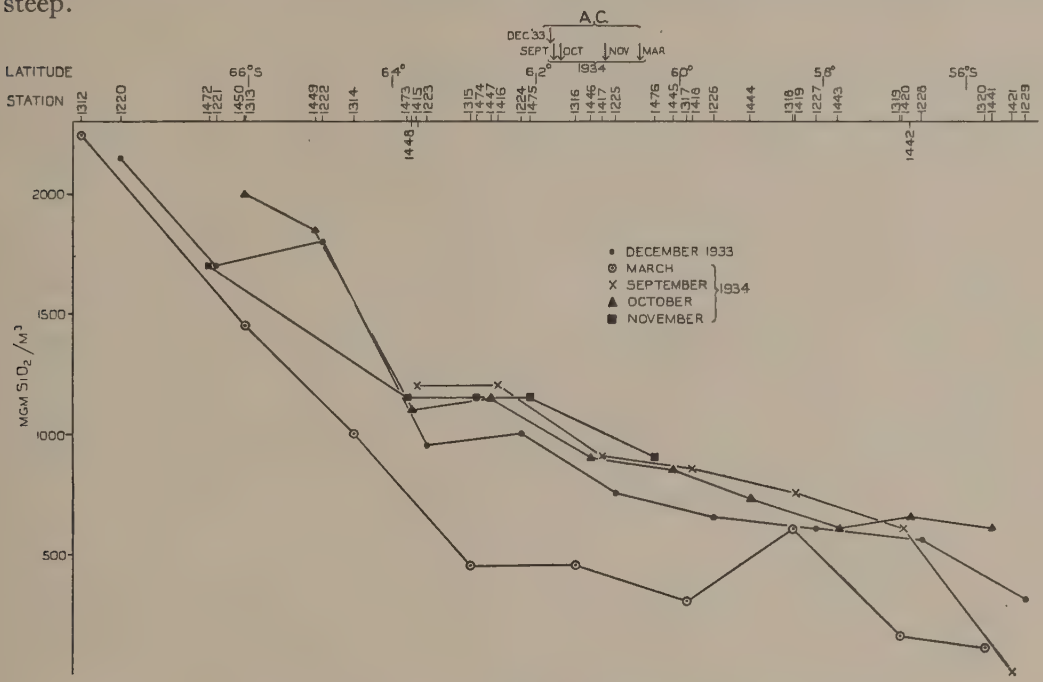

Fig. 17. The mean integral average silicate content of the 0–100 m. layer in 80° W.

It is safe to assume that the average silicate content of the 0–100 m. layer in February 1934 at about 66° S was of the order of 1100 mg., and, as we know that in October it was 2000 mg., we may conclude that a minimum *net* withdrawal of 45 per cent of the available silicate content took place at this latitude. It is impossible to give even an estimate of the consumption at the Antarctic convergence until observations are made in January and more in March.

SUB-ANTARCTIC SURFACE WATER

PHOSPHATE AND SILICATE CONTENTS AT THE SURFACE

Owing to the fact that the majority of the observations by the ships of the Discovery Committee has been made in Antarctic waters, there is not sufficient evidence to give a complete account of the seasonal variation in the nutrient salt content of the surface water in the sub-Antarctic zone. The data that are available were collected chiefly during the circumpolar cruise of R.R.S. 'Discovery II' in 1932. We have more data at the southern end of the zone than just south of the subtropical convergence.

In the Drake Passage (section 1, Plate III) sub-Antarctic surface water in mid-April 1930 (Sts. 385–388) had a surface phosphate content of 91 mg. just north of the Antarctic convergence and 74 mg. on the continental shelf near Cape Horn. In the Scotia Sea, south of the Falkland Islands, the surface value was 72–78 mg. in late March 1934 (Sts. 1323–1325) and 82 mg. in late September 1934 (Sts. 1423–1424). The value of 82 mg. south of the Falklands is surprisingly low for late September and is probably explained by reason of a southward movement of low phosphate water in this region in winter. This explanation is supported by biological evidence of the presence of a temperate-water species, *Chaetoceros decipiens*. Immediately after the observations in each month south of the Falkland Islands we have data from just north of the Antarctic convergence north of the South Orkney Islands. These observations gave a surface value of 83 mg. in April 1934 (St. 1338) and of 108 mg. in early October 1934 (St. 1435).

Observations made along 30° W in the western part of the South Atlantic Ocean (section 2, Plate IV) in April 1931 (Sts. 668–671) showed that the surface value in sub-Antarctic water varied from 79 mg. in the south to 73 mg. at the most northerly station in the zone, with a probable value of about 60 mg. just south of the subtropical convergence. These values indicate that regeneration was in progress when the observations were taken. In late April 1933 at St. 1162 in the eastern part of the South Atlantic Ocean (section 3, Plate V), a surface value of 73 mg. was recorded in the southern part of the zone. The order of this value agrees very well with that found previously in 30° W.

In the sub-Antarctic zone south of Cape Town in late March 1935 (Sts. 1556–1558, section 4, Plate VII), the surface phosphate value varied from 38 to 89 mg. from north to south. In October 1930 in a section south-south-west from Cape Town towards Bouvet Island (Sts. 449–451), the surface content in sub-Antarctic water varied southwards from 50 to 91 mg. Farther to the east between the Crozets and Durban (section 6, Plate X), in the third week of May 1934 (Sts. 1367–1369), the surface phosphate content was 98 mg. in the south of the zone and decreased to 74 mg. at the most northerly station, whilst in early March 1935 at St. 1553 in 49° 35·1′ S, 30° 44·4′ E (section 4, Plate VII), the surface value at the southern boundary of the zone was 88 mg. North of Marion Island at St. 1565 in 44° 04·7′ S, 37° 21·9′ E, the surface content was 60 mg. in mid-April 1935; the position of this station was nearer to the subtropical convergence than to the Antarctic convergence. In a section in early May 1932 across the sub-Antarctic zone between Enderby Land and Fremantle (section 7, Plate XII, Sts. 866–870), the surface phosphate content decreased from 110 mg. in the south to 72 mg. in the north.

South of Australia in early June 1932 the phosphate content in the surface water of the sub-Antarctic zone (section 9 from the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia, to Melbourne, Sts. 892–895) varied between 101 and 37 mg. from south to north (Plate XIV). The value of 101 mg. at the southern end of the zone probably represents very nearly the maximum surface value in sub-Antarctic water. South of the Tasman Sea between Melbourne and the ice-edge in 61° 25′ S, 154° 26′ E (section 10, Plate XV, Sts. 899–903), the surface value of sub-Antarctic water increased from 43 to

95 mg. southwards in the third week of June 1932, whilst a week later on the return section (11) between the ice-edge in 61° 05′ S, 158° 26′ E, south of the Tasman Sea, and North Cape, New Zealand (Sts. 921–924, Plate XVI), the southernmost sub-Antarctic station had a surface value of 73 mg., a value which decreased to 38 mg. at the northern end of the zone.

In the South Pacific Ocean it is only in the western part that we can give any data for the whole width of the sub-Antarctic zone. This is due to the fact that except near New Zealand we have no exact knowledge at present of the position of the subtropical convergence which in mid-South Pacific lies north of 35° S. In early September 1932 between Wellington, New Zealand, and the ice-edge north of the Ross Sea (Sts. 942–949, section 12, Plate XVII), the surface value increased southwards across the zone from 51 to 106 mg. In the third week of January 1934 section 13 was made from the ice-edge at the eastern entrance to the Ross Sea to Auckland, New Zealand (Sts. 1276–1280, Plate XIX). This latter section will serve to contrast with that of late winter in September 1932 from Wellington, New Zealand. In January the main phytoplankton outburst is finished in this zone, whilst in early September it has not yet begun. The phosphate results in the January section showed that the surface value fell from 82 mg. in the south of the zone to 14 mg. in the north, although the presence of some subtropical surface water of low phosphate content is probably responsible for the very low value of 14 mg.

In the course of a W-shaped cruise (sections 12, 14, 15 and 16) across the South Pacific Ocean in mid-September to early October 1932 a number of observations were made in sub-Antarctic water at Sts. 962–967, 967–970 and 976–978 (Plates XVII, XXI, XXIII and XXV). The subtropical convergence was not crossed in any of these sections, and consequently no values for the northern boundary of the sub-Antarctic water can be given. The surface content varied between 114 mg. at the most southerly stations and 38 mg. at the most northerly one in 41° 03·1′ S, 126° 03·9′ W.

In the eastern part of the South Pacific Ocean in 80° W we have data from four sets of observations in March, September, late October and late November; the data are mostly restricted to the southern end of the zone. In March (Sts. 1317–1320), the surface phosphate content varied from 90 to 67 mg. between 60° and 55¾° S; in mid-September (Sts. 1417–1421), surface values varied between 97 mg. in 61° S and 71 mg. in 55° 22′ S; in late October the most southerly station gave a value of 86 mg. in 61¼° S, whilst values of 76 mg. were recorded farther north; in late November there was only one observation of 100 mg. at St. 1476 in 60° 20′ S, a somewhat high value for the time of the year.

As a summary of our present knowledge we can say that the surface phosphate content at the southern end of the sub-Antarctic zone is of the order of 100–110 mg. in winter and of about 70 mg. after the main phytoplankton outburst which in this zone probably starts in October. At the northern boundary winter values of 60–70 mg. are found in the South Atlantic and South Indian Oceans, but south of Australia and the Tasman Sea values in June were found to be as low as 37–43 mg. Immediately south of Wellington, New Zealand, the value previous to the phytoplankton outburst was 51 mg., whilst at the northern boundary of the zone in the central part of the South Pacific Ocean the value must be less than 38 mg. at this time. Values subsequent to the phytoplankton outburst in the northern part of the zone are of the order of 30–40 mg. in the South Atlantic Ocean and considerably lower in the western part of the South Pacific Ocean.

Some small indication is shown of a secondary autumnal outburst of phytoplankton on a small scale in this zone in May.

In March 1934 in the sub-Antarctic zone south of the Falkland Islands (Sts. 1323–1325), the surface content of silicate was less than 300 mg. In late September of the same year and in the same position the surface content was 550–600 mg. at Sts. 1423–1424. Just north of the Scotia Arc, north of the South Orkney Islands, two stations (Sts. 1338 and 1435 respectively) taken immediately after those south of the Falklands in March and September, gave surface values of less than 300 mg. in early April and of 750 mg. in early October.

In the third week of November 1933 the surface value south-west of Tristan da Cunha, at the northern boundary of the sub-Antarctic zone was zero, but at St. 1196 in 48° 15·6′ S, 23° 58·9′ W, just north of the Antarctic convergence, the surface value was 750 mg.

In the eastern part of the South Atlantic Ocean in March 1933 a surface content at St. 1162 in 46° 47·2′ S, 12° 39·4′ E was 350 mg. South of Cape Town in March 1935 the surface content throughout the entire zone was less than 250 mg. at Sts. 1556–1558 (section 4, Plate VIII). In April 1932 at Sts. 848 and 849 (section 5, plate IX) between Cape Town and Enderby Land, the sub-Antarctic surface water was 360 mg., a value which very rapidly increased to one of 2400 mg. on crossing the convergence into Antarctic surface water. North of Marion Island at St. 1565 in 44° 04·7′ S, 37° 21·9′ E in mid-April 1935, the surface value was less than 250 mg.; the position of this station was in the northern half of the zone.

Between the Crozets and Durban (section 6, Plate XI) in the third week of May 1934 at Sts. 1367–1369, the surface content north of the Antarctic convergence was less than 300 mg. and zero south of the subtropical convergence. At St. 1553 in 49° 35·1′ S, 30° 44·4′ E, a position just north of the Antarctic convergence, the surface content in early March 1935 was less than 250 mg. (section 4, Plate VIII).

We have no silicate data for the sub-Antarctic Zone between about 40° E and the area south of Australia, but in May 1932 along section 8 (Plate XIII) at Sts. 880–882 the sub-Antarctic water between Cape Leeuwin, Western Australia, and the ice-edge, south of Australia in 63° 41′ S, 130° 07′ E, had a surface content which increased southwards across the zone from a value of 60 to one of 240 mg.

South-east of New Zealand, towards the ice-edge north of the Ross Sea, we have two sets of observations, one (section 12, Plate XVIII, Sts. 942–949), made in early September 1932 and the other (section 13, Plate XX, Sts. 1276–1280) in the third week of January

1934. In September 1932 the silicate content in sub-Antarctic water increased from 310 mg. close to Wellington, New Zealand, to 570 mg. at the southern end of the zone. In late January 1934 the surface content was less than 200 mg. everywhere in the zone; indeed, it was even less than 200 mg. in the northern part of the Antarctic zone. The summer values of January 1934 indicate that the main phytoplankton outburst had removed all but a very small amount of silicate some time previously, as there was a very poor concentration of phytoplankton present at the time the silicate observations were made.

In the course of the W-shaped cruise (sections 12, 14, 15, 16) across the South Pacific Ocean in mid-September to early October 1932, the subtropical convergence was not crossed, but in sub-Antarctic water the silicate content of the surface decreased from a value of 450 mg. at 54° 02·8′ S, 142° 25·4′ W near the southern boundary of the zone to 200 mg. in 41° 03·1′ S, 126° 03·9′ W, a position some distance south of the subtropical convergence. Farther east at St. 976 in 59° 22′ S, 89° 03·9′ W at the southern end of the zone the silicate content of the surface was 720 mg., a value which decreased to 470 mg. at 55° 18·4′ S, 80° 08·1′ W in early October 1932.

At 80° W there are five sets of observations in the southern part of the zone, the most northerly of these being in 55° 11·3′ S. In late December 1933 (Sts. 1225–1229), the surface content decreased northwards from 750 to 200 mg.; in March 1934 at Sts. 1317–1320 the silicate had been reduced to zero at the southern end of the zone, increasing, probably by regeneration in situ, a short distance farther north to a value of 450 mg. only to fall again to zero throughout the remainder of the section which finished in 55¾° S; in mid-September 1934 at Sts. 1417–1421 the surface value was greatest of all, the contents ranging from 850 mg. at the southern end of the zone to zero in 55° 22′ S; in late October 1934 at Sts. 1441–1446 the surface content was as high as 550 mg. at the northern end of the section in 55° 39′ S increasing to 800 mg. at the southern end of the zone. The fact that the surface value was zero at 55° 22′ S in September and as much as 550 mg. in a position a few miles away 41 days later must be due to the presence of water of low silicate content coming from the north in September.

The discussion of the surface phosphate content of sub-Antarctic water shows that only a tentative summary can be made. Similarly the silicate data show that many more observations are needed before an accurate picture can be obtained either of the distribution or of the seasonal variation in this zone. In winter the southern part of the sub-Antarctic zone has a surface content of about 700 mg., the eastern part of the South Pacific Ocean having perhaps a slightly greater content. The northern end of the zone has an approximate content of 0–300 mg. in winter. Summer values for the southern and northern parts of the zone are of the order of less than 200 mg. and between zero and less than 200 mg. respectively.

SUBTROPICAL SURFACE WATER

PHOSPHATE AND SILICATE CONTENTS AT THE SURFACE

Even less data exist for the nutrient salt content of subtropical surface water than for the sub-Antarctic water; our observations are mostly confined to data obtained during passages to and from Antarctic regions, except round South Africa where more work has been done.

In the western part of the South Atlantic Ocean (section 2, Plate IV, Sts. 673–677) in late April 1931 in 30° W the surface content of water in the subtropical zone was of the order of 8–10 mg.; the content dropped to zero immediately tropical water was encountered.

In the third week of November 1933 Tristan da Cunha was undoubtedly in the subtropical zone, the subtropical convergence lying well to the south by as much as 5–6° of latitude. St. 1188 in 41° 56′ S, 15° 08·6′ W, south-west of the island, was taken in subtropical water and had a surface content of 32 mg.

In the eastern part of the South Atlantic Ocean no differentiation of tropical and subtropical surface waters can be made by inspection of the surface content of phosphate as is possible in the western part of the same ocean. Thus in section 3 (Plate V), in mid-April 1933 in the eastern side of the ocean the surface content of phosphate did not drop to zero until St. 1182 (3° 20·8′ S, 8° 37·2′ W) was reached. At this station the surface temperature was 28·44° C. and the salinity was falling towards the north, whereas at St. 1180 (10° 30·8′ S, 4° 41·6′ W) with a surface temperature of 26·41° C. the surface phosphate content was 16 mg.; in this section subtropical surface water had a surface phosphate content which varied from 19 to about 10 mg. from south to north across the zone. Thus in the eastern part of the South Atlantic Ocean quite an appreciable quantity of phosphate can exist in tropical water, whereas as we have seen in the western part of the ocean the surface phosphate content was reduced to zero immediately tropical water was encountered in 28° 30′ S. The fact that the phosphate content of tropical surface water in the eastern part of the South Atlantic Ocean is not reduced to zero until the equator is almost reached must be due to the effect of the Benguela current which transports water with a surface content of about 25 mg. (in August) from the region west of Saldanha Bay into lower latitudes. In the western part of the ocean the surface water in low latitudes is supplied from the South Equatorial and Brazil currents in which the phosphate has been used up.

It has been observed that in general the plankton in the subtropical parts of the eastern and western halves of the South Atlantic Ocean is very different in concentration. The plankton in the eastern half of the ocean is rich compared with that in the western part. This difference must undoubtedly be connected with the difference in phosphate content in the two halves of the ocean.

Around the coasts of South Africa and south of this area rather more data are available. The waters surrounding South Africa are subject to subtropical and tropical influences. The Cape Peninsula is surrounded by subtropical surface water, but towards the east the Agulhas current brings almost tropical water, whilst on the west coast of South Africa upwelling of cold water increases the phosphate content in the surface. In late August 1930 a section (Sts. 414–421) was made from the subtropical convergence in 40° 28′ S, 16° 52′ E towards Cape Town. The surface content decreased from a value of 58 mg. at the southern end of the zone (where a mixture with sub-Antarctic surface water had increased the content) to 35 mg. at the last deep station before the coast was reached. At the actual coastal station which was situated on the continental shelf, upwelling had increased the surface content to 51 mg.

West of Saldanha Bay five observations were made within 100 miles of the coast in the third week of August 1930. These stations (408–412), were made in the Benguela current and had a surface phosphate content ranging from 20 to 27 mg. In early September 1930 a section was made south-east from Port Elizabeth (Sts. 424–435); this section cuts across the Agulhas and return Agulhas currents. The coastal station had a high surface phosphate of 49 mg. which was due to upwelling caused by the Agulhas current, whose surface water had a content of 26 mg. This value increased towards the south-east to about 35 mg. and then at the most southerly station where the salinity was slightly lower than is generally associated with subtropical water, it rose to 56 mg., possibly owing to admixture with sub-Antarctic surface water. East of Durban five stations (436–440), in late September 1930 showed that the surface phosphate content in the Agulhas current at this position and time of the year was 16 mg.

The observations around South Africa which have been referred to above were all made in August and September which are late winter months. In late March 1935, however, two subtropical stations (1554 and 1555), which were situated south of Cape Town, showed that the surface content of phosphate in subtropical water may be reduced to zero at this time of the year. The phytoplankton catches at these two stations were negligible and far too small to have been the immediate cause of the withdrawal of all the phosphate from the photosynthetic layer. There remains the possibility that a secondary outburst of phytoplankton activity in February or early March was responsible for the removal. It would require a season's intensive work to test such a possibility, which however, is supported by inshore investigations near Cape Town (private communication). If, as Dr Hart believes, the main phytoplankton outburst in subtropical waters occurs in September, when as our own results have shown there is an appreciable quantity of phosphate in the surface layer, it is reasonable to suppose that this available phosphate is quickly removed. Sts. 1554 and 1555 were taken in late March, and it is again reasonable to argue that regeneration of phosphate will have occurred in situ between September and March, and yet there was no phosphate in the surface layer at these stations. If, as we have postulated, a secondary outburst of phytoplankton occurred in February it would account for the absence of phosphate in late March. The September observations were of course made in 1930 and the March data in 1935, and the possibility of annual variation must not be forgotten. For instance, in the western part of the South Indian Ocean some observations made in the subtropical zone (Sts. 1566–1569), in the second week of April 1935 between Marion Island and

Durban, showed that the surface phosphate content was zero throughout the entire zone. A month later in the previous year in subtropical water between the Crozets and Durban (Sts. 1370–1373), the surface phosphate value was 20 mg. in the south of the zone and less than 5 mg. near the coast at Durban.

At the subtropical zone stations (section 7, Plate XII, Sts. 871–876), across the South Indian Ocean between Enderby Land and Fremantle, the surface phosphate in May 1932 was 48 mg. in the south of the zone and decreased to 10 mg. near Fremantle. The subtropical convergence is found not very far south of Melbourne and Tasmania, and we have only one observation in subtropical water south of Melbourne; this was at St. 896 in June 1932 when the surface content was 18 mg. In the same month off the east coast of Tasmania at Sts. 897 and 898 subtropical surface water had a content of 26 mg. which increased to 33 mg. just south of the island.

In subtropical water west of North Island, New Zealand, in early June 1932 the surface phosphate content was of the order 28–32 mg. (Sts. 925–928). East of North Island, New Zealand, there is only one observation which was made in late January 1934 when the surface content was only 10 mg. at St. 1281. Owing to the low latitude of the subtropical convergence in the central and eastern parts of the South Pacific Ocean there are no phosphate observations available in this zone, although it is certain that off the west coast of South America considerable quantities of phosphate must exist in the surface layer in this zone in order to maintain the very large concentrations of plankton which are known to be present.

It is difficult to summarize the distribution of phosphate content throughout the subtropical zone owing to the relatively small number of observations which are spread over several months of the year. However, it is possible to say that at the southern end of the zone a minimal surface content of 5–10 mg. has been found in January, March and April, whilst maximum phosphate seems to occur in the months of May, June, July, August, September, and exceptionally in November, and to be greater than 30 mg.—possibly as much as 50 mg. in some months. At the northern end of the zone we have only figures for March and April when 5–10 mg. were found in the South Atlantic, but in April 1935 in the western part of the South Indian Ocean the phosphate in the surface layer at the northern end of the zone had been reduced to zero. The eastern part of the South Atlantic Ocean has a greater surface phosphate content in this zone than has the western half.

In the South Atlantic Ocean very few observations of silicate content have been made in the subtropical zone. In late November 1933 at the southern end of the zone, south of Tristan da Cunha, the surface content was less than 300 mg. The eastern part of the South Atlantic Ocean had a surface content of about 200 mg. throughout the zone in late March 1933.

South of Cape Town in late March 1935 (Sts. 1554 and 1555, section 4, Plate VIII), the silicate content of the surface water was less than 250 mg. from the station nearest the coast to the subtropical convergence. In the second week of April 1932 (section 5, Plate IX, Sts. 844–847), between Cape Town and Enderby Land, the subtropical water had a surface content of 260 mg. in the north increasing to a value of 410 mg. in the south of the zone. In the third week of May 1934, i.e. just over two years later, silicate was at zero in the surface water from the Crozets to Durban (Sts. 1370–1373), whilst exactly three years later in the second week of April 1935 between Marion Island and Durban (Sts. 1566–1569) there was less than 250 mg. of silicate throughout the zone. Evidently although there is not much silicate in the surface water in the subtropical zone in April–May there are indications of an annual variation.

South of Australia our observations have been restricted to two stations south of Fremantle in the third week of May 1932, when (Sts. 877 and 878, section 8, Plate XIII) the surface value was of the order 160–210 mg.

East of New Zealand but quite close to the North Island, the surface value in late January 1934 at St. 1281 was zero. There are no observations in subtropical water elsewhere in the South Pacific Ocean.

Obviously our present knowledge of the silicate content of subtropical water is insufficient for any real discussion and all we can say is that in the months of January, March, April and May very little silicate is present in this water; even this small quantity may sometimes be absent.

ANTARCTIC INTERMEDIATE WATER

PHOSPHATE AND SILICATE CONTENT

The Antarctic intermediate current has its origin in the region 100–200 miles north of the Antarctic convergence and consists of the heavier and colder portion of the mixed water found there. It sinks towards the north and can be traced as a poorly saline layer situated below the highly saline surface and subsurface layers and above the highly saline warm deep water. It is characterized by an intermediate salinity minimum and, in certain parts of the ocean, in particular the western part of the South Atlantic Ocean, by an intermediate temperature minimum. This temperature minimum is caused by the bottom part of the current having a lower temperature than the upper layers of the warm deep water. The colder water in the bottom of the intermediate current is a remnant of the cold stratum of the Antarctic surface water. Whether the intermediate temperature minimum is shown or not the boundary between the intermediate and warm deep currents is usually shown by the temperature gradient becoming very much less steep at the boundary zone.

The Antarctic surface water has a strong northerly component of movement: the phosphate in this layer is contained either in the plankton or in the surface layer itself. The density of the phytoplankton in Antarctic surface water varies enormously with the season of the year, and it follows that the amount of phosphate in the surface layer in the Antarctic zone also varies with the season; this is because, when the phytoplankton concentration is increasing enormously, as it does at the time of the main outburst, it is using up and withdrawing phosphate, amongst other nutrient salts, from the surrounding sea water. Consequently the seasonal effect is of paramount importance to any consideration of the nutrient salt concentration in the Antarctic intermediate current which has within it a large proportion of water that was originally in the surface layer in the Antarctic zone. The longitudinal section of phosphate content in the western part of the South Atlantic Ocean (Plate IV) shows that the Antarctic intermediate current has always a large phosphate content, and that north of the Rio Grande ridge this current is the seat of the greatest concentration of phosphate. If we consider the Antarctic intermediate layer as a large body of water which flows with a northerly component and mixes at its upper and lower boundaries with other layers of lower phosphate content, a slow and steady falling off of the phosphate content towards the north would be expected. In practice this uniform fall of phosphate content is not found and, because the Antarctic intermediate layer has a characteristic minimal salinity, we can, by noting the phosphate content of the layer at this level, trace northwards the changes of phosphate content in the nucleus of the current. As an example of the manner in which the phosphate content at the depth of minimum salinity of the intermediate current varies towards the north, the observations in section 3 in the eastern part of the South Atlantic Ocean will be utilized, and the data are given below in Table V. The reason why the phosphate content at the depth of minimum salinity of this layer does not fall smoothly towards the north must be sought in the seasonal variation in phosphate of this water at its place of origin and in the surface layer in the Antarctic zone. At the time when the main outburst of phytoplankton is at its maximum, a large amount of phosphate is withdrawn from the photosynthetic zone of the Antarctic surface water which itself is travelling towards the north. The phosphate which has been thus withdrawn is held by the phytoplankton and by the zooplankton which feeds on the plant life. Some of these organisms travel northwards and sink at the Antarctic convergence, and it might be argued that the sum total of phosphate, either free in the water or held by the plankton, which arrives at the Antarctic convergence is the same as was originally in the water before the main outburst of phytoplankton activity. The zooplankton organisms that can move out of the northward going layer by vertical migration, are, however, responsible for the

Table V

Station	1162	1165	1167	1173	1175	1177
Latitude	46° 47·2′ S	41° 01′ S	36° 01·3′ S	29° 39′ S	23° 33·4′ S	17° 54·1′ S
Depth of salinity minimum	234	900	850	980	650	675
P_2O_5 at salinity minimum	81	156	106	99	76	120
Station	1179	1180	1181	1182	1183	1184
Latitude	12° 29·8′ S	10° 30·8′ S	6° 59·3′ S	3° 20·8′ S	0° 07′ N	3° 46·2′ N
Depth of salinity minimum	970	810	770	630	625	780
P_2O_5 at salinity minimum	128	127	95	116	110	121

consumption of a considerable amount of phytoplankton: also diatoms tend to die and sink out of the Antarctic surface layer. Thus at the time of the main phytoplankton outburst a large amount of phosphate is removed from the photosynthetic zone of the surface layer, and is not all transported northwards to sink across the convergence into sub-Antarctic water. Similarly in the southern end of the sub-Antarctic zone phosphate is removed from the surface layer, and some of this is lost to the Antarctic intermediate current by migration of plankton and sinking of dead phytoplankton organisms. Thus if two seasons are considered, (1) the winter months when phytoplankton activity is at a minimum and the phosphate content of the surface layer is greatest and (2) the time when the main phytoplankton outburst is at its height and large amounts of nutrient salts are being consumed, it is possible to trace the underlying causes of the seasonal variation of phosphate content in the Antarctic intermediate current. In the Antarctic and sub-Antarctic zones the phosphate content of the surface layer is at a maximum in winter, and in consequence, the Antarctic intermediate current which has its origin in the area of mixing 100–200 miles north of the Antarctic convergence and is mainly composed of Antarctic and sub-Antarctic surface waters, will have its greatest nutrient salt content in winter. Similarly the nutrient salt content will be least when the waters which make up this current have their minimum nutrient salt contents. This will be immediately after the time of the main phytoplankton outbursts of October–November in the sub-Antarctic zone, and November–December in the Antarctic zone. If the path of the intermediate current is followed northwards by plotting the phosphate content at a definite position within its structure, i.e. at the depth of minimum salinity, it will be possible to see what kind of a curve is obtained for the south to north distribution of phosphate within this current. In Fig. 18 the phosphate values in Table V have been plotted against latitude. The resulting curve consists of a series of maxima and minima. The positions of these maxima and minima correspond very well with those found in the curve (which is also shown in Fig. 18) of the minimum salinity of the current when plotted against latitude. Similarly, a very close correspondence is found if the oxygen and silicate contents at the depth of minimum salinity of the layer are plotted against latitude (see Figs. 19–21). Deacon (*Discovery Reports*, VII, p. 224 *et seq.*) has used the oxygen and salinity values at the depth of minimal salinity of the intermediate current as a means of obtaining an estimate of the northerly component of this current. I have heard criticisms of this method on the ground that the various maxima and minima in the curve are due to some sort of wave action and not to seasonal variation. It is remarkable, however, that the curves show very many correlations; for instance, if we consider the effect of winter formation of the intermediate current which involves high phosphate, silicate and salinity, and low value of oxygen content, we find the curves show that phosphate, silicate and salinity are maximal and oxygen content is minimal at the same positions of latitude. Similarly, summer formation of the intermediate water would involve low contents of phosphate, silicate and salinity, with a high oxygen content: the positions of minimal contents of phosphate, silicate and salinity, and maximal oxygen content agree extremely well. It is, therefore, reasonable to suppose that the crests

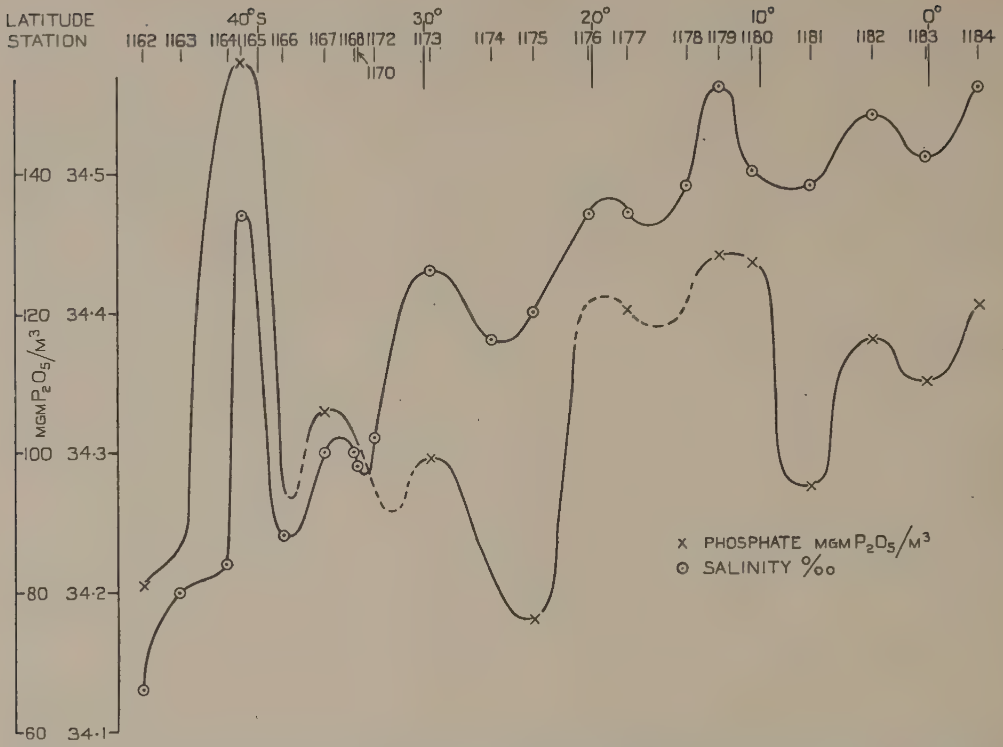

Fig. 18. Graph showing the variation of the phosphate content and salinity from south to north at the depth of minimum salinity in the Antarctic intermediate current in the eastern part of the South Atlantic Ocean.

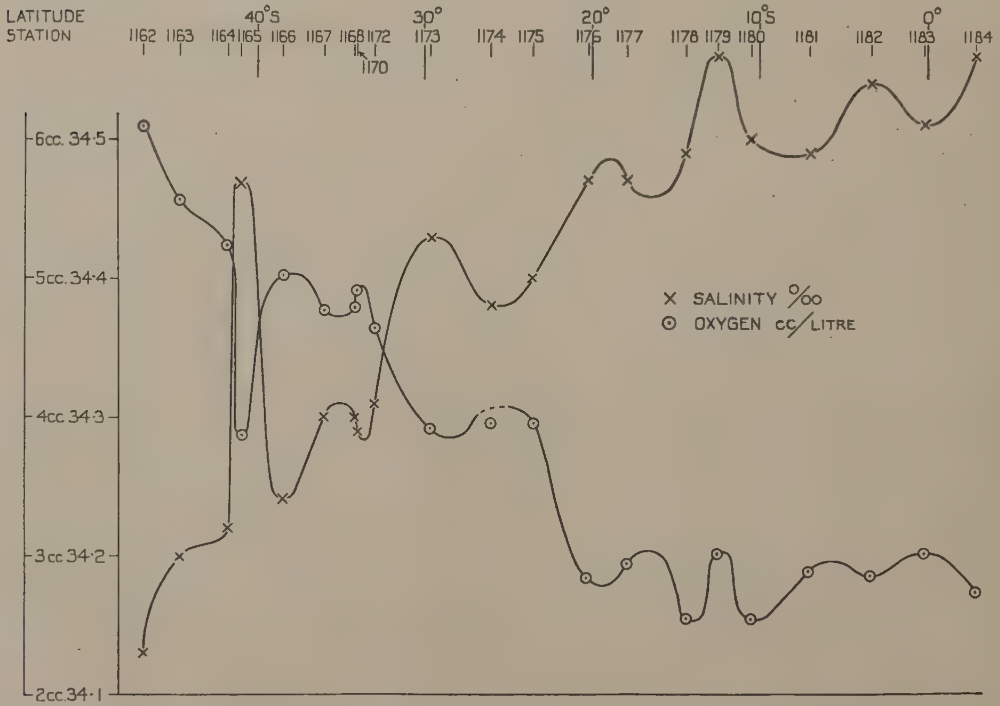

Fig. 19. Graph showing the variation of salinity and oxygen content from south to north at the depth of minimum salinity in the Antarctic intermediate current in the eastern part of the South Atlantic Ocean.

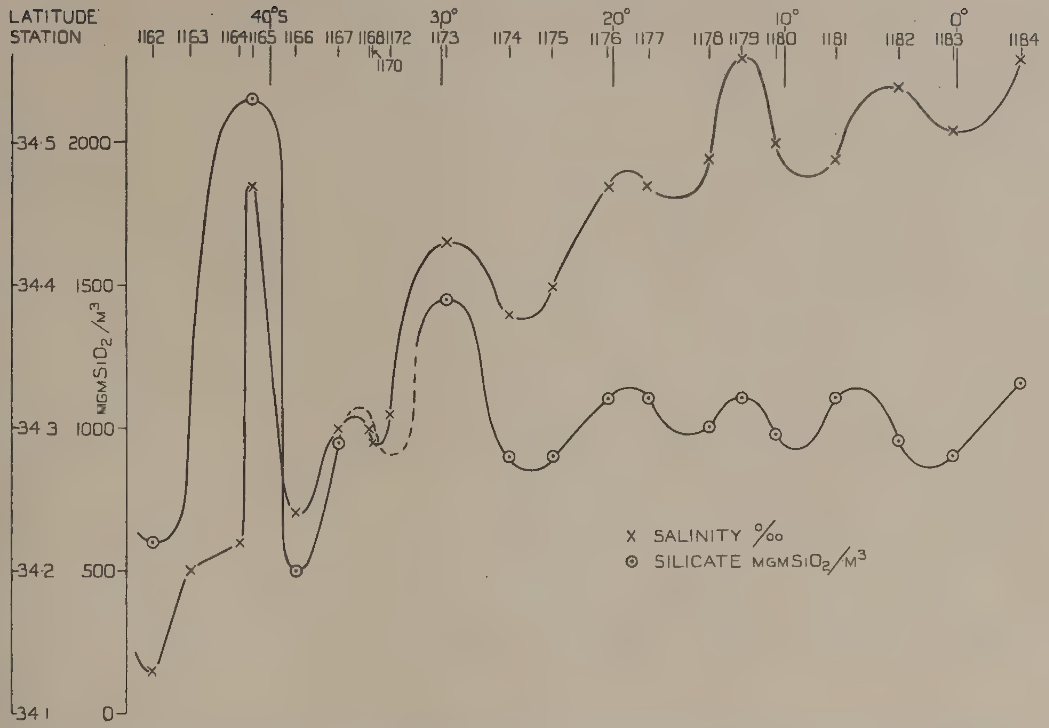

Fig. 20. Graph showing the variation of salinity and silicate content from south to north at the depth of minimum salinity in the Antarctic intermediate current in the eastern part of the South Atlantic Ocean.

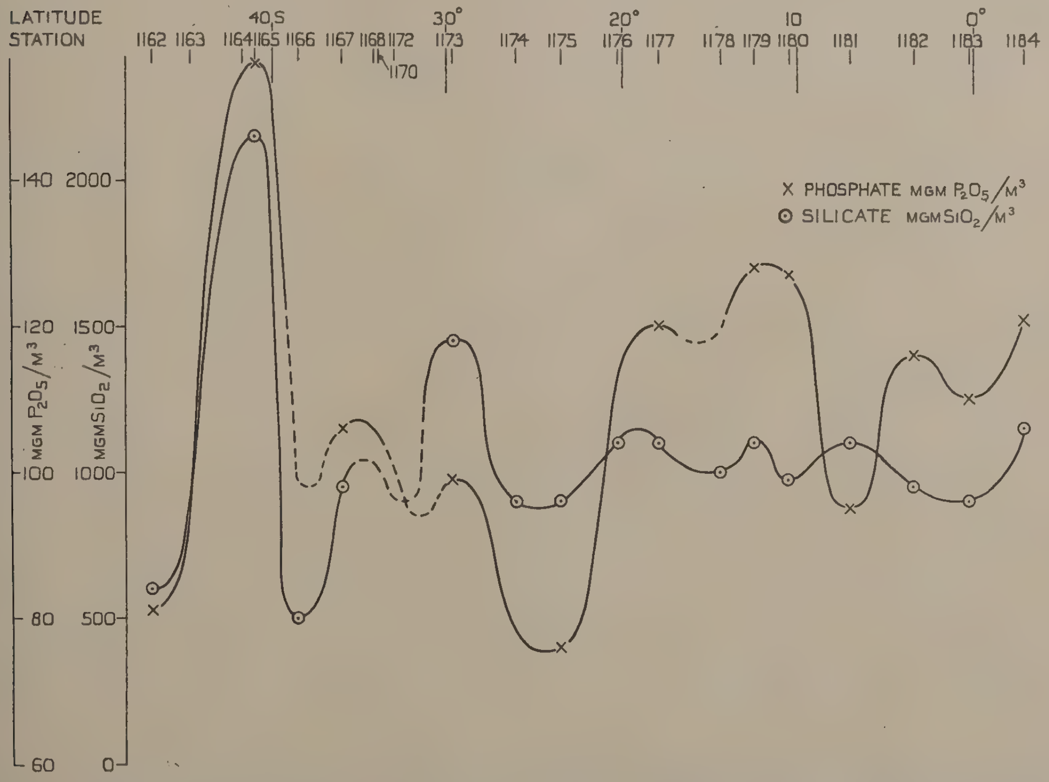

Fig. 21. Graph showing the variation of phosphate and silicate content from south to north at the depth of minimum salinity in the Antarctic intermediate current in the eastern part of the South Atlantic Ocean.

and troughs of the phosphate and silicate curves are due to seasonal variation in the composition of the constituent waters of the current. Thus by using phosphate or silicate values we have other checks on the approximate values for the northward velocity of this current which were obtained from salinity and oxygen results (Deacon, *ibid.*). With the completion of the circumpolar cruise of R.R.S. 'Discovery II' in 1932 and from subsequent longitudinal sections in 1933–7 there are available a number of sections from the pack-ice northwards up the South Atlantic, Indian and Pacific Oceans. From these sections it may be possible to estimate the approximate speed not only of the northerly component of velocity of the intermediate current but also the southerly component of the warm deep current.

Until the upper and lower boundaries of the Antarctic intermediate current have been determined more accurately no accurate summary can be made of the nutrient salt content throughout the thickness of the layer. Since, however, the intermediate current is characterized by a salinity minimum, a description of the phosphate content at this depth will give some idea of the distribution of phosphate within the current.

When the boundary between the layer above the intermediate current and the intermediate water itself is crossed the phosphate content increases enormously, the places of origin and the constitution of the two waters being widely different.

Plate IV shows the phosphate content in the western part of the South Atlantic Ocean in 30° W (Sts. 663–699). Maximum phosphate occurs in the area 38°–43° S which has been described by Deacon (1933, p. 234) as the position where the greatest vertical mixing occurs between the north-going Antarctic intermediate current and the south-going warm deep water; phosphate is being added to the warm deep water in this region. North of the Rio Grande ridge in about 35° S the maximum phosphate content of the whole water column is not found in the warm deep water, but is situated close to the depth of the salinity minimum of the Antarctic intermediate water. Between 46° 42½′ S and 14° 27¼′ N the phosphate content of the intermediate current at this position of minimum salinity varies in a series of crests and troughs between 136 mg. and 98 mg., the average value being greater to the north of the section. The fact that north of the Rio Grande ridge the maximum content of phosphate is found in or close to the depth of the salinity minimum of the intermediate current, and that the content in this position of the current increases slowly northwards must be intimately connected with the transport of plankton (which probably decomposes chiefly in this layer) by the Antarctic intermediate current. A study of the numbers of organisms in the zooplankton population at the depth of the salinity minimum of the intermediate water in this section will probably be of great interest in this connexion. As we have seen, north of the Rio Grande ridge, phosphate is maximal at a depth close to the salinity minimum of the intermediate water; this maximum is sometimes greater than the winter values of the constituent waters of the intermediate current, at 26° 06½′ S, for example, it is 137 mg. at 1000 m. Hence it is reasonable to postulate that considerable regeneration of phosphate is taking place in the intermediate current, which has an initially high content, and this regeneration is due to the decomposition of plankton which sinks mainly at the Antarctic convergence and in the area of mixing 100–200 miles farther north. Maximum phosphate is found, however, in the region 38°–43° S, i.e. well to the north of the Antarctic convergence where an enormous mortality of phytoplankton occurs, as is evident from the position of the belt of diatom ooze. Phosphate must be carried northwards in the current either free or held by the plankton. Organically combined phosphorus may also be present in the sinking water. Phytoplankton in the south consists mainly of diatoms which have a siliceous skeleton. If at the Antarctic convergence and in the area of mixing 100–200 miles north of it there is a heavy mortality of diatoms, the skeletons will tend to sink, and some of the descending debris will pass through the south-going warm deep water and eventually arrive at the bottom to form the diatom ooze and the high silicate concentration in the bottom water. The phosphorus which was originally withdrawn by the phytoplankton will now be distributed between the zooplankton and its excretions, and the dying phytoplankton. It is probable that phosphorus is excreted as organically combined phosphorus and as such will be unavailable for other plankton until after decomposition to phosphate, a process which may take months for completion. During this time the Antarctic surface water is travelling northwards and, north of the Antarctic convergence, becomes part of the Antarctic intermediate current.

The distribution of zooplankton individuals caught in closing nets in the longitudinal section in 30° W showed that although the numbers decreased towards the north across the Antarctic convergence the bulk of the zooplankton sank into deeper layers. That is, an increase in numbers occurred in the layer between 500 and 750 m. at 46° 42½′ S and also in 43° S in the layer between 750 and 1000 m. It does not necessarily follow that this always happens, as the zooplankton has considerable powers of vertical migration, but it may be expected that any dying organisms would be carried into the Antarctic intermediate layer. We know that phosphate is at a maximum in the region 38°–43° S in the mixed water, and since oxygen is minimal and hydrogen-ion concentration is greatest in this mixed water it can be argued that decomposition and regeneration must be greatest in this region. It is probable that decomposition of plankton and regeneration of phosphate is proceeding everywhere in the area between the Antarctic convergence and 38°–43° S, but the process may be more intense in these latitudes with the result that maximum phosphate is found in this position.

In March–April 1933 in section 3 in the eastern part of the South Atlantic Ocean between 46° 47′ S and 3° 46′ N (Sts. 1162–1184), the phosphate content at the salinity minimum of the Antarctic intermediate current again progressed in a series of crests and troughs from south to north. The section is shown in Plate V. The actual limits of the phosphate content at this depth are between 76 mg. and 157 mg., but the latter figure stands alone and the general variation is between 81 mg. and 128 mg. The high value of 157 mg. occurs in the subtropical zone at a depth of 970 m. at St. 1165 in 41° 01′ S, 9° 34·3′ E; this position corresponds in latitude to that of maximum phosphate content in the western part of the same ocean. It seems reasonable to suggest that maximum decomposition in this layer is occurring either at or immediately south of St. 1165.

North of the Antarctic convergence maximum phosphate in this section occurs either at or close to the depth of the salinity minimum of the intermediate current. In general there is slightly less phosphate in the eastern side of the South Atlantic Ocean than in the western side, and this accords with the fact that the strength of the intermediate current is not quite so great in the eastern part of the ocean as in the west.

In late August 1930 a section was made south-south-west from Cape Town (Sts. 414–421, 449–452). The phosphate content at the salinity minimum of the intermediate water varied between 92 mg. and 154 mg., being greatest at the northern end of the section. The depth of the salinity minimum of the layer varied about 200 m. throughout the section and in general was between 600 and 800 m. Phosphate was greatest at the positions farther from the surface.

In late March 1935, south of Cape Town (Sts. 1554–1557, section 4, Plate VII), the phosphate content at the salinity minimum of the intermediate water varied between 141 mg. and 116 mg., being again greatest towards the north.

In September 1930 a section in a south-easterly direction was made from Port Elizabeth towards the subtropical convergence (Sts. 424–435). The phosphate content of the salinity minimum in the intermediate current was 157 mg. near the coast of South Africa and between 125 mg. and 135 mg. at the southern end of the section. Near the coast, however, the depth of salinity minimum of the layer was 1500 m. as against 800 m. towards the south. This difference of depth of the intermediate water may well be significant, as it is reasonable to suppose that there are less plankton organisms at the greater depth. It would seem that south of South Africa the phosphate content of the intermediate current is greater than in the Atlantic Ocean proper. The northward movement of the current in the area south of South Africa is small compared with that in the Atlantic Ocean farther to the west, and it is possible that the slowing down of the northward movement in this current has the effect of restricting the decomposition into phosphate from being spread over such a large area as in the Atlantic. The amount of North Indian Ocean deep water in the upper layers of the warm deep water in the vicinity of South Africa is not known for certain, but the upper layers do contain water from this source. Our section (6, Plate X) to Guardafui in 1935 showed that the North Indian deep water has a very high phosphate content, so that any mixing between the bottom of the Antarctic intermediate current and the upper layers of the warm deep current, which latter contains water of North Indian origin, would result in phosphate being added to the lower part of the intermediate current.

The phosphate distribution in the Antarctic intermediate current in the western part of the Indian Ocean is shown in Plate X. North of the Atlantic-Indian cross-ridge the depth of the salinity minimum of the layer is about 800 m., but when the section comes within the sphere of the Agulhas current system the depth of the whole layer is depressed so that the salinity minimum is found at about 1500 m. only to rise again closer to the surface towards the north. The phosphate at this position in the current is of the order 135–145 mg. at the greater depth and between 95 mg. and 129 mg. where the salinity minimum is closer to the surface. The distribution fluctuates towards the north in a series of crests and troughs which do not appear to be as regular as the similar curve in the eastern part of the South Atlantic Ocean. South of the latitude of Durban (about 30° S) the phosphate is greatest in or close to the salinity minimum of the intermediate current, but north of this latitude the maximum content is found in the upper layers of the warm deep water. In this respect the Antarctic intermediate current in the western part of the South Indian Ocean is different from that in both the eastern and western South Atlantic Ocean, where, north of the Rio Grande ridge in the west and, of the latitude of approximately 46° S in the east, maximum phosphate always occurs in the intermediate current

The phosphate content of the intermediate current along section 7 across the South Indian Ocean, between the ice-edge in 48° 43·7′ E and Fremantle, Australia, in May 1932, may be seen in Plate XII. The phosphate content at the salinity minimum varied between 108 mg. and 147 mg. but was in general of the order 120–125 mg., the high value of 147 mg. being exceptional and occurring in the shallower water west of Fremantle. The order of these values is slightly less than that of the stations south of Cape Town. In the section across the South Indian Ocean the maximum content of phosphate was not found in the Antarctic intermediate water but in the upper layers of the warm deep water. This warm deep water is of complex origin, but the upper part of the current contains a large proportion of North Indian Ocean deep water which has a high phosphate content. The presence of North Indian deep water may be the reason why the maximum phosphate content occurs in the deep water and not in the intermediate water.

South of Australia and Tasmania the content at the salinity minimum of the intermediate current in June 1932 along sections 9 and 10 varied between 112 mg. and 118 mg. and 121 mg. and 84 mg. respectively. These sections which were made between the ice-edge in 130° 07′ E and Melbourne (Sts. 887–896), and between Melbourne and the ice-edge in 154° 26·2′ E (Sts. 896–906), are shown in Plates XIV and XV. According to Deacon (1937, p. 69) the intermediate current has a very small volume and a high salinity south of Australia and Tasmania. He attributes this to the restriction placed on the northward flow of the intermediate current by the land-mass of Australia and partly perhaps to the fact that a large volume of highly saline water is forced to flow southwards in the subsurface layer in order to flow south of Australia. The northward flow of Antarctic surface water in the Antarctic zone itself may also be smaller owing to the relatively low latitude of the Antarctic Continent in this part of the ocean. At none of the stations north of the Antarctic convergence was there any indication of a temperature inversion. It was also found that the phosphate content of the intermediate current south of Australia is less than farther west as shown by sections 6 and 7 from Enderby Land to Guardafui and Fremantle. The intermediate layer has less phosphate south of Australia than has the warm deep water.

South of the eastern half of the Tasman Sea, Deacon (1937, p. 69) notes that the intermediate current has a slightly greater volume and is less saline than south of Australia. In Plate XVI, which shows a section between the ice-edge in 158° 24·5′ E and North Cape, New Zealand (Sts. 912–928), it may be seen that the phosphate content at the salinity minimum of the intermediate current is greater than south of Australia and varies between the narrow limits of 118 mg. and 125 mg.

In September 1932 the depth of the intermediate current south of Wellington in the direction of the pack-ice north of the Ross Sea varied considerably. Plate XVII shows the phosphate content along section 12 (Sts. 942–956). The variation in the depth of the nucleus of the intermediate current has a corresponding variation in the phosphate content at this depth. The variation of phosphate content at the salinity minimum was between 88 mg. and 127 mg., the greatest value being towards the south. A somewhat similar section (13) was made in January 1934 (Sts. 1267–1281), the vertical section of which is shown in Plate XIX. Again there was a large variation in depth of the salinity minimum, and the phosphate values at this depth varied correspondingly between 79 mg. and 128 mg. The section differed from that of September 1932 in that the greatest phosphate content of the intermediate water was found near New Zealand, whereas in September 1932 the greatest values were found towards the south.

During September 1932 in the central part of the South Pacific Ocean the phosphate content at the nucleus of the intermediate current was greater than it was east of New Zealand and was of the order 100–125 mg. Maximum phosphate was not found in the intermediate water but in the highly saline deep layer.

In 80° W our observations did not extend north of 55° S, and the mixed water forming the intermediate current had not sunk to depths greater than 400–600 m. The phosphate content at the salinity minimum of the intermediate water fell from south to north and exhibited seasonal variation. Thus in 1934 it varied as follows: March 115–130 mg., September 80–95 mg., and October 88–109 mg. Maximum phosphate was found at greater depths, usually between 1000 and 1500 m., in the warm deep water.

In summarizing the phosphate data of the Antarctic intermediate current, attention must first be drawn to the importance of seasonal variation in nutrient salt content of the constituent waters of this current. As a consequence of this seasonal variation the phosphate content at a particular level in the current such as the depth of minimum salinity, does not fall off smoothly towards the north. When the phosphate content at this depth is plotted against latitude a series of maxima and minima are seen in the curve. These maxima and minima are considered to have a real significance and may be the basis for an approximate estimation of the speed of this current in a northerly direction.

In the western part of the South Atlantic Ocean north of the Rio Grande ridge the intermediate current contains more phosphate content than the warm deep water. Maximum phosphate appears to exist in the region 38°–43° S which is considered to be the position of maximum decomposition of the plankton which was originally in the Antarctic surface water. In the eastern part of the South Atlantic Ocean maximum phosphate in the intermediate current is found in 41° S, a position comparable with that in the western part of the ocean.

In the western part of the South Atlantic Ocean the phosphate content at the depth of minimum salinity of the intermediate current north of the Rio Grande ridge varied between 98 mg. and 136 mg., being, in general, greatest to the north. In the eastern side of the same ocean the content at the corresponding depth ranged from 76 mg. to 156 mg. between 46¾° S and 3¾° N, the high value of 156 mg. being exceptional. In general there is slightly more phosphate in the intermediate current in the west than in the eastern part of the South Atlantic Ocean.

In the western part of the South Indian Ocean, south of Durban (30° S), maximum phosphate appears to lie in or close to the depth of the salinity minimum of the intermediate layer. North of this latitude, the influence of the North Indian deep water with its very high phosphate content causes the maximum to lie at greater depths. In this respect the intermediate current in the western part of the South Indian Ocean differs from that in the South Atlantic, where phosphate is maximal in the intermediate current north of 35° S, in the west and north of 46° S in the east.

In the western part of the South Indian Ocean the phosphate content at the nucleus of the intermediate current between 42½° S and 7° N varied between 95 mg. and 147 mg., the greater amounts being found when the salinity minimum was depressed by the immense volume of water in the Agulhas current system.

A diagonal section across the South Indian Ocean in a south-west to north-east direction showed that in this part of the ocean the intermediate current was not the seat of maximum phosphate which on the contrary was found in the warm deep water. At the depth of minimum salinity of the intermediate water the phosphate ranged from 108 mg. to 147 mg. but was usually of the order of 120–125 mg.

South of Australia the phosphate content of the intermediate current was less than that of the western part of the South Indian Ocean. South of Tasmania less phosphate was present in the intermediate current, and values of the order of 84–121 mg. were recorded at the salinity minimum, but south of the eastern part of the Tasman Sea there was more phosphate in the layer, and the corresponding values were from 118 mg. to 125 mg.

South-east of New Zealand the depth of the intermediate current varied considerably with corresponding variations in the phosphate content at the depth of minimum salinity. Two sections differed as to the direction in which the phosphate content of the intermediate current increased.

In the western part of the South Pacific Ocean the phosphate content at the salinity minimum of the intermediate current varied between about 80 mg. and 128 mg. in the two years in which we have observations. In the central part of the same ocean slightly more phosphate was recorded, the variation being between 100 mg. and 125 mg., but these figures are only for the southern part of the sub-Antarctic zone. In 80° W seasonal variation was indicated, the content being highest in March and lowest in September.

As we have seen above when phosphate leaves the Antarctic zone either free in the surface layer or in combination with the plankton, it does so by sinking with the Antarctic surface layer into sub-Antarctic water at the Antarctic convergence; it is later found as a high content in the Antarctic intermediate current. Phosphate is also lost to the Antarctic zone in the bottom water but to a lesser degree.

Silicate is withdrawn in the Antarctic zone from the photosynthetic layer of the surface water by phytoplankton and Radiolaria, although chiefly by the former. Part of the phytoplankton is consumed by the zooplankton, and the silicate skeletons are excreted immediately by the animal organisms. These excreted skeletons and other dead diatoms sink to the bottom, and although a proportion pass into the southward-flowing warm deep water, others pass into the bottom water causing a very high silicate content in this layer. The existence of the belt of diatom ooze near the Antarctic convergence is evidence of a tremendous mortality of diatoms in this position. Some of the free silicate in the Antarctic surface water together with the zooplankton and unconsumed phytoplankton travels north-eastwards to the Antarctic convergence and sinks into sub-Antarctic water eventually forming part of the intermediate current. Thus silicate leaves the Antarctic zone in two northward-going layers, the Antarctic intermediate and bottom currents. Because of the low concentration of silicate in the sub-Antarctic surface water the mixed water formed 100–200 miles north of the Antarctic convergence does not have a large silicate content. On the other hand, the Antarctic bottom current has a very large silicate concentration, between 5000 and 7000 mg. in the Antarctic zone. Thus although silicate leaves the Antarctic in two ways, the greater portion is carried by the Antarctic bottom water.

Plate VI shows a vertical section of silicate content along section 3 in the eastern part of the South Atlantic Ocean between 69° 20·8′ S and 3° 46·2′ N. As may be seen a moderate amount of silicate leaves the Antarctic zone at the convergence in the sinking surface water and a much larger concentration in the bottom water which also has a northerly component of movement. The lower layers of the warm deep water are seen to be returning this high concentration southwards again at quite a high latitude. The silicate content at the depth of the minimum salinity of the intermediate current varies between 500 mg. and 2150 mg., but the upper limit is usually of the order of 1000 mg. with very small variation north of 26° S. The distribution of silicate from south to north at the depth of minimum salinity of the intermediate current also forms a series of maxima and minima which, however, are not so pronounced as in the phosphate curves. An enormous mortality of diatoms occurs in or immediately south of the vicinity of the belt of diatom ooze, and the silicate skeletons of the diatoms are excreted rapidly after consumption of the plant life by the zooplankton. Since sinking of dead and excreted diatoms occurs it would not be expected that the curve of silicate distribution would show as marked a variation as does the similar curve for phosphate distribution. The variation that does occur, however, must be related to the seasonal variation in silicate content of the constituent waters of the intermediate current. In the section under review maximum silicate at the depth of minimum salinity of the current is found at St. 1165 in 41° S at 900 m.; this was also the depth and position of maximum phosphate content of the current. Since both phosphate and silicate are maximal for the intermediate current at St. 1165 it is reasonable to assume that maximum regeneration in the current takes place at this position.

South of Cape Town the depth of the salinity minimum lies at about 1500 m.

where the surface water belongs to the Agulhas current system, and at about 600 m. outside the influence of this system. The difference in depth of the intermediate current is due to the large volume of tropical and subtropical water borne by the Agulhas current. The silicate distribution in this area is shown in Plate VIII, where it is seen that at Sts. 1554 and 1555 in section 4 the content at 1500 m. is of the order of 2400–2700 mg. against 1050–1900 mg. at 600 m. at Sts. 1556 and 1557 to the south of the Agulhas water. In April 1932 a section was made between Cape Town and the ice-edge north of Enderby Land. This section (5, Sts. 845–855) is shown in Plate IX, from which, cf. Deacon, 1937, Plate XIV, it is seen that the silicate content at the depth of minimum salinity was greatest towards the north, being of the order of 2200 mg. in the north and of 1600 mg. at 48° 14·6′ S in the south.

Between the Crozets and Durban in May 1934 the silicate content at the depth of minimum salinity increased from 800 mg. at about 350 m. at St. 1369 in 42° 25·8′ S, just south of the subtropical convergence, to a value of 2750 mg. at a depth of 1500 m. at St. 1372 in 34° 01·8′ S. A year later the silicate content a short distance to the west of the previous section was 1800 mg. at the salinity minimum of the intermediate current in the south, a value which increased to 2750 mg. in the north.

Plate XI shows the vertical distribution of silicate content along section 6 between the ice-edge in 64° 38′ S, 44° 16′ E and Guardafui in 11° 32′ N; the section is composed of two sets of observations from different years. The silicate content at the salinity minimum of the layer increased northwards from a value of 800 mg. at 42° 25·8′ S as the depth of the current became greater, until a value of 2400 mg. was reached at 1500 m. at St. 1570 in 28° 42′ S. North of this latitude the depth of the current lessened and the nucleus was usually found between 600 and 800 m., the silicate content ranging from 1500 mg. to 2200 mg. in a series of crests and troughs.

The vertical distribution of silicate in section 8 south of Australia in May 1932 between Cape Leeuwin and the pack-ice in 130° 07′ E is shown in Plate XIII. The intermediate current had a content of 1900 mg. at the depth of minimum salinity near Australia, the content falling southwards as far as 43° 53·1′ S where it was 1400 mg., rising again to 1900 mg. at St. 881 in 47° S.

There are no observations of silicate content south of the Tasman Sea.

South-east of New Zealand two sets of observations are available along sections 12 and 13, one, Sts. 942–948, in September 1932 and the other, Sts. 1277–1281, in January 1934. The vertical sections are given in Plates XVIII and XX respectively. In the September section from Wellington to the pack-ice north of the Ross Sea the depth of the minimum salinity of the intermediate current varied between 800 and 300 m., being deepest at St. 947 in the deep basin about half-way between the Antarctic and subtropical convergences. Near New Zealand the content at the nucleus of the current was 700 mg., a value which fell towards the south as far as 49° 24·6′ S where it was only 450 mg., and south of this position it increased to a value of the order of 1500–1700 mg. In the January section from the pack-ice north of the Ross Sea to Auckland the depth of the salinity minimum increased from 300 m. at 53° 58′ S to 900 m. at 47° 16·5′ S and to

800 m. near New Zealand. The silicate at the nucleus of the current increased towards the north from a value of 650 mg. to one of 2350 mg. near New Zealand, whereas in the previous section the silicate content increased southwards in this current. At present we know very little of the effect of seasonal and annual variations in nutrient salt content in the deep currents, but unless the differing amounts of silicate present in the two sections can be related to some such variation it is difficult to explain the observations of 1932 and 1934. It will be remembered that the phosphate content at the depth of minimum salinity of the intermediate current increased towards the south in September 1932, whilst in January 1934 the greatest value was found towards the north, near New Zealand. The section must be repeated for a full understanding of the problem.

In the sub-Antarctic region of the central part of the South Pacific Ocean the minimum salinity was usually found at a depth of 800–1000 m., where a silicate content of 1000–1200 mg. was recorded in September 1932.

In 80° W our observations do not extend north of 55° S, but south of this latitude the average silicate content at the salinity minimum in sub-Antarctic water was of the order of 650–1100 mg.

The amount of silicate data of the intermediate current at present available renders the writing of a summary of this knowledge somewhat more difficult than for phosphate. However, a very important fact emerges from a consideration of the vertical sections of silicate content. Silicate leaves the Antarctic zone in two currents, the sinking Antarctic surface water and the Antarctic bottom water. Both currents have northerly components of movement, and the major portion of the silicate that leaves the Antarctic zone does so in the bottom current. On account of the heavy mortality of diatoms in the region of the Antarctic convergence and the fact that the silica skeletons of the diatoms are excreted almost immediately after consumption of the plant organisms by the zooplankton, the amount of silicate carried out of the Antarctic zone in the form of plankton in the sinking surface water is relatively not as great as the amount of phosphate. On the other hand, the Antarctic bottom water has a very large silicate content owing to the solution of excreted and dead diatoms which sink into it within the Antarctic zone. Also the silicate content of sub-Antarctic surface water, a component of the Antarctic intermediate current, is small. These reasons show why the series of maxima and minima obtained in the curve expressing the distribution from south to north of silicate content at the depth of the salinity minimum of the intermediate current, is less marked than is shown in the corresponding curve for phosphate content. The variation that does occur, however, is correlated with that of the phosphate curve and is ascribed to the seasonal variation of silicate in the constituent waters of the current.

In the eastern part of the South Atlantic Ocean maximum silicate content at the depth of minimum salinity occurs in the same latitude as does maximum phosphate. Apart from a value of 2100 mg. at this position in 41° S, the silicate content at this depth in the current varies between about 800 mg. and 1100 mg. South of South Africa, where the intermediate current lies at a greater depth in the Agulhas current region, a higher content is found and up to 2750 mg. was recorded at the nucleus of the current.

In the western part of the South Indian Ocean the intermediate current has a higher content than in the eastern South Atlantic. Outside the region of the Agulhas current the content at the salinity minimum varied between about 1500 mg. and 2200 mg. between 22° and 1° S.

South of Australia the silicate value at the nucleus of the current was of the order of 1900 mg. near Fremantle, falling southwards to about 1400 mg. and then increasing to 1900 mg. again at the most southerly station in the sub-Antarctic zone.

South-east of New Zealand two sections made in different years gave contrary results and need to be repeated in subsequent cruises.

WARM DEEP WATER

PHOSPHATE AND SILICATE CONTENT

For the following description of the warm deep water I am chiefly indebted to Deacon (1937). This current can be recognized everywhere as a layer of high salinity underlying a poorly saline layer. In the Antarctic zone it is also recognized by its relatively high temperature between the low temperatures of the surface and bottom waters. In the sub-Antarctic and subtropical zones it underlies poorly saline sub-Antarctic and Antarctic intermediate waters.

In the South Atlantic Ocean it can be traced from its place of origin in the North Atlantic, where highly saline water sinks from the surface to great depths and flows southwards, rising at the Antarctic convergence to a depth of about 250 m. Near South Georgia this water climbs towards the south as far as about 52°–53° S without interruption. South of 53° S the deep water belongs chiefly to a current from another source, flowing from the southern and eastern parts of the Scotia Sea. North of the Weddell Sea the temperature of the warm deep water decreases suddenly towards the south in about 60° S, and between the warm deep water found north of this latitude and a further warm region near the Antarctic Continent the deep water is so cold that it can only belong to an eastward movement of deep and bottom waters from the Weddell Sea. Against this cold current the southward movement of North Atlantic deep water comes to an abrupt end. In the eastern part of the South Atlantic Ocean the North Atlantic deep water reaches as far south as 55°–56° S.

In the region south of the Indian Ocean the warm deep current flows as far south as the continental slope of Antarctica. In the neighbourhood of the slope it bends towards the west into the Atlantic Ocean, where it is found as a warm current to the south of the cold current which flows eastwards from the Weddell Sea. The southward movement in the western part of the Indian Ocean is mainly formed of North Atlantic deep water, but it also contains water in its upper layers from a similar origin in the northern part of the Indian Ocean (Clowes and Deacon, 1935). In the eastern part of the subtropical and sub-Antarctic zones of the Indian Ocean the deep water is less saline, colder, and poorer in oxygen than the deep water in the west. These properties suggest that it is formed by the mixing of North Indian deep water with Antarctic intermediate and bottom waters and North Atlantic deep water.

In the Pacific Ocean the deep-water circulation differs very considerably from that of the Atlantic and Indian Oceans. Except in the western part of the ocean and in the extreme eastern part near the Drake Passage, the most saline water is found in the southern part of the Antarctic zone, the salinity being greatest in about 65° S. The temperature, salinity and oxygen content of this highly saline water are plainly very similar to those of the deep water found south of Australia and very different from those of the deep water found farther north in the Pacific Ocean itself, and they suggest that the current has its origin chiefly in an eastward current from the Indian Ocean. Tracing the history of the water farther back it must be regarded as North Indian deep water and probably North Atlantic deep water, both waters having been considerably modified during their progress towards the south and east by mixing with the Antarctic surface and bottom waters. There are, however, indications that there may be a second though smaller source of highly saline deep water in the western part of the ocean north of New Zealand.

The warm deep waters of the various oceans have considerable seasonal variations of phosphate content. This must follow from the fact that there is a seasonal variation in the density of plankton and phosphate content in the Antarctic surface water. Since the phosphate content of the warm deep water is influenced by that of the Antarctic surface water it must also show a seasonal variation in phosphate content. For this reason it is not possible to draw charts of the distribution of phosphate content in any particular stratum of the warm deep water, as for instance at the depth of maximum salinity, since our observations are spread over several months in different years. When more data become available it may be possible to estimate an average content for any given month in various parts of the oceans and then construct charts giving the distribution of phosphate in the deep waters. The following data, obtained in two cruises of January and March 1934 show a great difference of phosphate content at the salinity maximum of the warm deep water at two positions in the ice-edge region of the South Pacific Ocean.

Station	Position	Date	P_2O_5 mg./m.^{3} at salinity maximum
1249	67° 11·9′ S, 108° 41·5′ W	7. i. 1934	115
1303	67° 04·8′ S, 111° 50·0′ W	4. iii. 1934	156
1257	67° 52·4′ S, 129° 27·5′ W	11. i. 1934	123
1295	68° 01·4′ S, 134° 14·8′ W	28. ii. 1934	151

Thus Sts. 1249 and 1257 were made in early January 1934 and had a phosphate content at the salinity maximum of the order of 115–123 mg., whilst Sts. 1295 and 1303 had corresponding values of the order of 151–156 mg. about 6–8 weeks later. These differences, which occur with corresponding differences in salinity and oxygen content, must be related to seasonal variation. The phosphate content of the warm deep water also varies from year to year, as, for example, at Sts. 1154 and 1525 which were situated at the ice-edge in about 10° E and made in 1933 and 1935. The following data were obtained:

Station	Position	Date	P_2O_5 mg./m.^{3} at salinity maximum
1154	69° 20·8′ S, 9° 33·8′ E	12. iii. 1933	108
1525	68° 41·8′ S, 10° 34·8′ E	18. ii. 1935	132

The data shown in the above table are typical of the differing contents of the warm deep water at the same position in different years.

The phosphate content of the warm deep water is always large, and in the Antarctic zone the actual maximum in the water column usually occurs in this layer.

In the Drake Passage (section 1, Plate III), maximum phosphate occurs in the warm deep water in both the Antarctic and sub-Antarctic zones. In the Antarctic zone the maximum is of the order of 140–150 mg. and is situated in the upper part of the warm deep water, whilst in the sub-Antarctic zone the maximum, though still in the warm deep layer, is at a greater depth and is of the order of 130–140 mg.

In the Antarctic zone of the South Atlantic Ocean the phosphate content increases rapidly across the discontinuity layer which separates the Antarctic surface water and the warm deep layer. In the Scotia Sea and around South Georgia the phosphate content of the whole column is a maximum in the upper layers of the warm deep current; this maximum is usually of the order of 140–160 mg., the content falling off slightly through the remainder of the layer and sometimes increasing again in the bottom water. Some stations worked in 1931 and 1934 gave a maximum phosphate content in the bottom water in the region between Elephant Island and the South Shetland Islands. This region is one in which Deacon (1937, p. 108) says there is evidence for the formation of Antarctic bottom water on a small scale, by the complete vertical mixing of the whole water column during winter so that the cold surface water finds its way directly into the bottom layer.

The distribution of phosphate at the depth of maximum temperature and salinity of the warm deep water in the Scotia Sea northwards from the South Orkney Islands to the Antarctic convergence on three occasions in the season 1934–5 is shown in Fig. 22. The greatest variation at both depths in the current occurred in April, when the content varied between 127 mg. and 174 mg. at the upper level and between 135 mg. and 165 mg. at the depth of maximum salinity. In January and October the variation between the two levels and from north to south was much less.

To the east of the South Sandwich Islands the warm deep water, though possessing a high phosphate concentration, was not in 1934 the seat of the maximum which was found in the bottom water in this locality.

The phosphate distribution along section 2 in the western part of the South Atlantic Ocean in 1931 is given in Plate IV, which shows a vertical section in 30° W from 57° 36′ S, to 14° 27¼′ N (Sts. 661–699). The warm deep water is of North Atlantic origin, and nearly as far north as the southern subtropical convergence it is the layer of richest phosphate content. The maximum south of this convergence is of the order of 140–150 mg. and is situated in the upper layers of the warm deep water in Antarctic zone stations, sinking to about 1000 m. in the sub-Antarctic zone; in the neighbourhood of the subtropical convergence (St. 671) it is found in the mixed water between the north-going Antarctic intermediate current and the south-going warm deep water. In this section phosphate is a maximum in the region 38°–43° S, whilst, north of 35° S, the latitude of the Rio Grande ridge, the warm deep water contains less phosphate than the intermediate current, and the maximum of the warm deep water is only 80–100 mg. compared with 120–140 mg. in the Antarctic intermediate current.

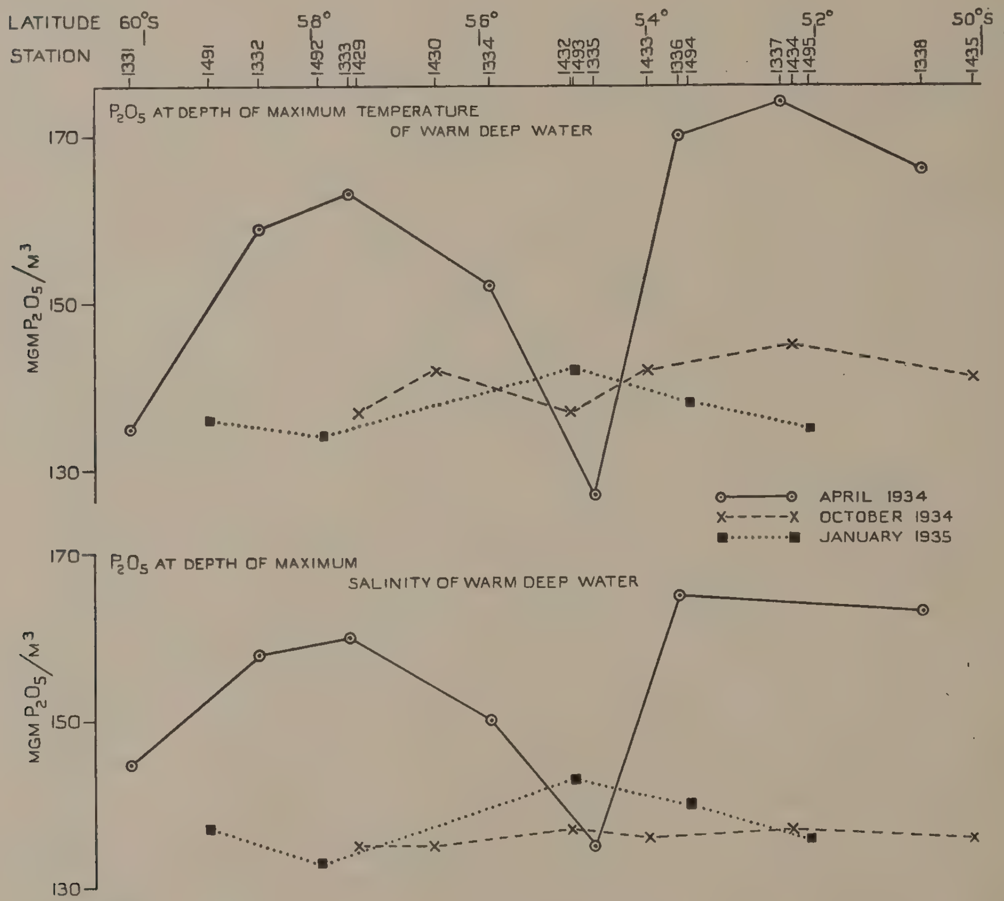

Fig. 22. Graph showing the variation of the phosphate content from south to north at the depths of maximum temperature and salinity of the warm deep water in the Scotia Sea, north of the South Orkney Islands.

In Plate V we have a good picture of the phosphate distribution along section 3 in the eastern part of the South Atlantic Ocean between 69° S and 3° N (Sts. 1154–1184).

Unfortunately, north of 12½° S the observations only extend just below the intermediate current. This section was made in March–April 1933 as compared with that in the western part of the ocean which was made in April–May 1931. The phosphate content throughout was lower in the eastern section, particularly in the Antarctic zone, where the maximum content occurred in the upper layers of the warm deep water and was of the order of 115–120 mg. compared with 140–150 mg. in the western section. Attention has already been drawn to the difference in the phosphate content of the warm deep water at the most southerly position, St. 1154, in the eastern section as compared with a station, St. 1525, made in almost the same position 3 years later. Also in February–March 1935 some observations were made along section 4 from the ice-edge in 66½° S, 42½° E towards Cape Town (Sts. 1543–1553, Plate VII), the phosphate content was maximal in the warm deep water in the Antarctic zone and was of the order of 140–150 mg. This amount, though not as great as that found in the western part of the South Atlantic in 1931, is more comparable than the values found in the eastern part of the South Atlantic in 1933. It would be expected that the average content of the warm deep water would not be so great in the eastern half of the South Atlantic as in the west because the strength of the Antarctic intermediate current is less in the eastern half. The general lowness of the 1933 observations in the eastern part of the ocean must be due to annual variation of which we have very little data at present.

In the Southern Ocean south of the Atlantic Ocean the phosphate content of the deep layers is rather confusing in that the maximum content is found sometimes in the warm deep layer and sometimes in the Antarctic bottom water. Thus south of 60° S in 1934 the maximum was mainly in the bottom water, but in 1935 it appeared about equally in the two currents. At the stations where the maximum appeared in the bottom water I have calculated the difference between this maximum value and the content in the upper layers of the warm deep water. On an average this difference amounts to about 6½ mg. but frequently is lower. We know from the longitudinal sections 2 and 3 (Plates IV and V) in the South Atlantic Ocean that the return of phosphate to the Antarctic zone occurs via the warm deep water and that phosphate leaves the Antarctic in the bottom water in addition to that which is carried out in the sinking surface water. What we do not know at present is the amount of mixing that occurs between the lower layers of the warm deep water and the bottom water, i.e. it is possible that when the phosphate maximum occurs in the bottom water it is because plankton has either sunk or been carried downwards in the warm deep water to decompose in the boundary layer between the two currents and that the bottom water becomes enriched by mixing. On the other hand, it is possible that the Denigès method of phosphate estimation is not sufficiently accurate under the conditions at sea in bad weather, to furnish such fine distinctions between the contents of water masses.

The upper layers of the warm deep water appear to have a content of about 135–145 mg. in the region south of 60° S in the South Atlantic Ocean; at the stations in the extreme south where the warm deep water flows towards the west and consists of water of mixed North Atlantic and North Indian Ocean origin, the upper layers of the current had a content of the order of 130–140 mg. in February 1935 as opposed to about 150–160 mg. in May 1934, an example of seasonal or annual variation in this current.

In March–April 1935 between the ice-edge in 42½° E and Cape Town (section 4, Plate VII), maximum phosphate at stations in the Antarctic zone was found at a depth of 100–200 m. in the south and 300–400 m. near the Antarctic convergence except at Sts. 1543, 1547 and 1549 where the maximum occurred in the bottom water. With these exceptions, the maximum, ranging from 140 to 150 mg., was always found in the upper layers of the warm deep water. In the sub-Antarctic zone the maximum content occurred at a greater depth but was still situated in the upper part of the current and was of the order of 142–148 mg. North of the subtropical convergence the maximum was found in the Antarctic intermediate current, the warm deep water having a lesser content of about 105 mg. at the depth of maximum salinity.

South-south-west of Cape Town in 1930 (Sts. 414–421) the phosphate maximum was situated in the mixed water between the intermediate and warm deep currents, whilst south-east of Port Elizabeth (Sts. 424–435) it was wholly in the intermediate water. South of the continental slope south of Cape Town the content at the depth of maximum salinity of the warm deep water was 154 mg., and south-east of Port Elizabeth the corresponding value was 143 mg.

In May 1934 along section 6 from the ice-edge in 44° E to north of the Atlantic-Indian cross-ridge the maximum phosphate content in the Antarctic zone occurred in the upper layers of the warm deep water at a depth of about 200–400 m., the actual maximum being of the order of 155–165 mg.; the section is shown in Plate X. North of the Antarctic convergence the maximum content was still found in the warm deep water but at a greater depth, about 1000 m. at the southern end of the sub-Antarctic zone and at 2000 m. south of the subtropical convergence, the maximum falling from about 160 mg. to 135 mg. from south to north. The section has been extended northwards to near Guardafui by using observations made in April-May 1935 which are included in the same plate (X). In the subtropical zone of the western part of the South Indian Ocean the warm deep water contained less phosphate than the intermediate current, its content being 120–130 mg. at the depth of maximum salinity as opposed to 135–145 mg. at the actual maximum in the intermediate current. Farther north in the tropical zone the phosphate content increased through the intermediate water to become a maximum in the warm deep water. North of 20° S this warm deep water is purely of North Indian Ocean origin, whilst south of this latitude the North Indian warm deep water occupies the upper portion of the current, the bulk of which is of North Atlantic origin. In the purely North Indian Ocean deep water the phosphate content becomes a maximum at or just below the depth of the salinity maximum of the layer. South of 20° S the phosphate becomes a maximum well above the depth of maximum salinity. Thus in addition to other characteristics it may be possible by reference to the phosphate content to distinguish in observations in the tropical zone the source of the deep water, i.e. if the maximum content is found close to the salinity maximum of the layer it is probable that the deep water is North Indian deep water.

Also north of 20° S the actual phosphate maximum increases towards the north, and the North Indian deep water has a greater content than the water of North Atlantic origin south of 20° S. As the section shows, the phosphate of the warm deep water increases from 139 mg. at a depth of 1500 m. in 18½° S to 161 mg. at 800 m. at 7° N. The level of the warm deep current rises towards the north, the depth of the salinity maximum rising from 3000 m. in 25° S to 1000 m. in 13¼° S and 400 m. in 7° N, whilst the depth of the maximum content of phosphate rises correspondingly from 1500 m. in 25° S to 900 m. in 7° N.

The western part of the South Indian Ocean differs from the western half of the South Atlantic Ocean where north of the Rio Grande ridge in 35° S the phosphate content of the warm deep water is less than that of the intermediate current. In the western part of the South Indian Ocean in the tropical zone the phosphate content is greatest in the warm deep water; the source of the very high content in this water is at present unknown. It is possible that the plankton carried northwards in the intermediate current decomposes at a lower latitude in the Indian Ocean than in the Atlantic, and that this decomposition takes place in the warm deep water which is travelling southwards. However, some further work is needed north and east of our section to help decide this question.

The phosphate content of the South Indian Ocean along section 7 between the ice-edge north of Enderby Land and Fremantle is shown in Plate XII. Throughout this section, which was made in April–May 1932, the phosphate content of the warm deep water was large, being greatest in the upper layers at about 150–600 m. in the Antarctic zone and progressively deeper in the sub-Antarctic and subtropical zones. At the southern stations in the deep basin west of the Kerguelen-Gaussberg ridge, the maximum phosphate occurred at a depth of about 150–300 m. and was of the order of 115–130 mg. At stations near and on the ridge the maximum was found closer to the surface at about 150 m. and was considerably greater, at about 140–160 mg. North-east of the ridge in the sub-Antarctic zone maximum phosphate was found at 800 m. in the south and as deep as 2000 m. to the north but always in the warm deep water; the maximum was never as great as that near the ridge but was of the order 145–155 mg. in the south and 130–140 mg. in the north. In the subtropical zone the phosphate content of the warm deep water was slightly greater than that in the northern part of the sub-Antarctic zone and the maximum was usually found at a depth of 1500–2000 m. except in the area of the west Australian current where it was deeper at 2000–2500 m.

In the southern half of the Antarctic zone south of Australia, along section 9 (Plate XIV), maximum phosphate occurred in the upper layers of the warm deep water where 140–150 mg. were found. North of about 56° S the maximum appeared to be less and was of the order of 130 mg., whilst in the sub-Antarctic zone it was found at a depth of 800 m. in the south and 1500–2000 m. in the north. Just south of the subtropical convergence and in the subtropical zone the warm deep water had a maximum content of 120–125 mg., which is slightly less than that of the intermediate current which contained 130 mg.

Two sections (10 and 11) between Melbourne and the ice-edge in 61° 24·7′ S, 154° 26·2′ E, and the ice-edge in 61° 05′ S, 158° 24·5′ E and North Cape, New Zealand, are shown in Plates XV and XVI. Near Tasmania the warm deep water had a phosphate content of about 130–140 mg. throughout. South of the subtropical convergence maximum phosphate was still found in the warm deep water and increased southwards from about 120 mg. to 135 mg., the depth of the upper part of the current rising from 2000 to 150 m. In the section from the ice-edge to New Zealand the warm deep water at the most southerly station (912) had a relatively low content of 103–112 mg. throughout, there being an entire absence of bottom water at this shallow station. North of St. 912 the content in the warm deep water increased considerably, and for stations in the Antarctic and sub-Antarctic zones the maximum content, ranging from 137 to 148 mg., was always found in this current with the exception of St. 922, where at 1500 m. as much as 155 mg. was recorded in the mixed water between the Antarctic intermediate and the warm deep currents. North of the subtropical convergence in the shallower water to the west of New Zealand the lowest observations were made in the intermediate current and no values are possible for the warm deep current. As may be seen from Plates XV and XVI, more phosphate was found in the warm deep current in the Antarctic zone in the east than in the west, south of the Tasman Sea.

South-east of New Zealand two sets of observations are available for discussion; these are shown as vertical sections 12 and 13 in Plates XVII and XIX. In September 1932 (section 12, Plate XVII), the phosphate content of the warm deep water increased slightly southwards from New Zealand, ranging in general from 130 mg. to 145 mg. with a peak value of 172 mg. in the upper layers at St. 951 which was situated on the Cape Adare-Easter Island ridge. In January 1934 (section 13, Plate XIX), the warm deep water decreased in phosphate southwards from New Zealand the content ranging from 160 mg. to 140 mg. at the maximum concentration.

From observations in the Antarctic and sub-Antarctic zones of the central part of the South Pacific Ocean in September 1932 it seems that the whole water column had a greater phosphate content than in the corresponding areas in the South Indian Ocean and south of Australia. Maximum phosphate occurred in the upper layers of the warm deep water in the Antarctic zone and was of the order of 150–160 mg. compared with 115–130 mg. west of the Kerguelen-Gaussberg ridge and 140–160 mg. on the ridge and 130–150 mg. south of Australia. This may be due to the fact that the deep water is derived mainly from sources rich in phosphate and not partly from a descending current of surface water, relatively poor in phosphate, such as the North Atlantic deep current. In the sub-Antarctic zone of the central part of the South Pacific maximum phosphate occurred at a lower depth in the warm deep water and was of the order of 150 mg.

Along the ice-edge in the far south of the Pacific Ocean many data exist as a result of intensive work in 1934. Two cruises were made across the ocean, one westwards in December 1933–January 1934, the other eastwards in February–March 1934. The phosphate of the warm deep water was always large, and at slightly less than half the total number of stations the actual maximum content of the whole water column occurred in the upper layers of the current; at the greater number it was situated in the highly saline bottom water in the area between 130° and 170° W in the western part of the deep basin in the Antarctic zone of this ocean. The phosphate content at the depth of maximum temperature, i.e. in the upper part of the current, averaged 130 mg. on the east to west cruise and 146 mg. on the west to east cruise. The two cruises took 18 and 16 days respectively and were separated by 37 days from the end of one to the beginning of the other. The return or eastward cruise was at a slightly higher latitude owing to the retreat of the ice-edge during the interval between the sets of observations. The difference in phosphate content at this depth in the current must be ascribed to seasonal variation. In the eastward cruise the content visibly increased from west to east, whilst on the westward journey the corresponding decline was not quite so obvious.

Along the routine line of stations in 80° W our observations covered only the Antarctic zone and part of the sub-Antarctic zone. The warm deep water was always the seat of the maximum content which usually occurred in the upper part of the current, ranging from 140 mg. to 150 mg. in most months; an exception, however, was recorded in March 1934 when considerably higher values of 150–170 mg. were found.

The preceding observations show that the phosphate content of the warm deep water varies both seasonally and annually, and for this reason the amount of data we possess is not sufficient to give an average content. The amounts of phosphate content given in parenthesis below refer to content at specific dates and may vary at other times; in the Antarctic zone the content is always large. In the western part of the South Atlantic Ocean maximum phosphate (140–150 mg.) occurs in the upper part of the warm deep current as far north as the Rio Grande ridge (35° S), north of which the Antarctic intermediate current contains more phosphate than the warm deep water (80–100 mg.). Less phosphate was found in the deep current in the eastern side of the South Atlantic than in the west—a maximum of 115–120 mg. in the Antarctic zone in March 1933 compared with 140–150 mg. in the west in April 1931.

South of 60° S in the Atlantic sector of the Southern Ocean maximum phosphate was found sometimes in the upper part of the warm deep water (135–145 mg.) and sometimes in the bottom water; the reason for this is at present not understood.

South of Cape Town maximum phosphate (140–150 mg.) occurred in the warm deep water at stations in the Antarctic and sub-Antarctic zones. North of the subtropical convergence the seat of maximum content was in the Antarctic intermediate current. Similarly, in the western part of the South Indian Ocean maximum phosphate was found in the warm deep water south of the subtropical convergence (155–165 mg. in the Antarctic zone and 135–160 mg. in the sub-Antarctic zone), whilst in the subtropical zone the maximum was in the intermediate current. In the tropical zone where the deep water is of North Indian Ocean origin it again occurred in the warm deep water and increased towards the north (139 mg. at 18½° S and 161 mg. at 7° N). The North Indian Ocean deep water has a greater content than the North Atlantic deep water.

Across the Southern Ocean between Enderby Land and Fremantle, Australia, maximum phosphate was always found in the warm deep layer, but south of Australia in the subtropical zone the maximum was found in the intermediate current. The content at the maximum in the Antarctic zone varied according to the position of the stations—those on the Kerguelen-Gaussberg ridge being greater (140–160 mg.) than those west of the ridge (115–130 mg.). North-east of the ridge in the sub-Antarctic zone as much as 145–155 mg. was found as a maximum content in the south and 130–140 mg. in the north. South of Australia in the Antarctic zone the maximum was 140–150 mg., the value falling towards the north. South-east of New Zealand two sections in 1932 and 1934 gave conflicting results. In the Antarctic zone of the central part of the South Pacific Ocean maximum phosphate appeared to be in the upper part of the warm deep water and this maximum (150–160 mg.) was considerably greater than that in a corresponding area in the South Indian Ocean and south of Australia.

In the ice-edge region of the South Pacific sector on two cruises which were separated by a short interval of time considerable variation of phosphate content in the warm deep water was found.

Longitudinal sections through each of the three main oceans in the southern hemisphere show that the return of silicate to the Antarctic zone is effected in the southward-flowing warm deep water. The major part of the silicate is returned in the lower part of the current, whilst a smaller proportion returns in the upper layers. The silicate content of the warm deep water is of paramount importance to the life cycle of the Antarctic plankton. In the Antarctic zone and parts of the sub-Antarctic zone we can fix the depth of the upper layers of the warm deep water by noting the position of the temperature inversion between the surface and warm deep currents. The maximum temperature of the warm deep water is found just below the temperature inversion referred to and represents the temperature of the upper part of the current. Another important level in the warm deep water may be fixed by the depth of the salinity maximum of the layer. If we discuss the silicate content at these two depths wherever possible, a good knowledge of the amount of silicate in this important water mass will be obtained.

On three occasions in 1934–5 a line of observations was made northwards from the South Orkney Islands to the Antarctic convergence. The silicate content at the depths of maximum temperature and salinity of the warm deep water has been plotted and is shown in Figs. 23 and 24. In April 1934 the most southerly station was situated in the very deep area just north of the islands and the silicate content at the depth of maximum temperature in the upper layers of the warm deep current fell from about 5500 mg. in the south to 2700 mg. just north of the Antarctic convergence. Between the latitudes of 53½ and 55° S an intermediate rise in silicate content in the upper part of the current occurred towards the north in all three sets of observations; this increase of silicate may be a permanent feature connected with a rise in the sea-bottom in this locality which causes upwelling. Very little conclusive evidence of seasonal variation at the depth of maximum temperature is shown, particularly in the middle part of the line of stations.

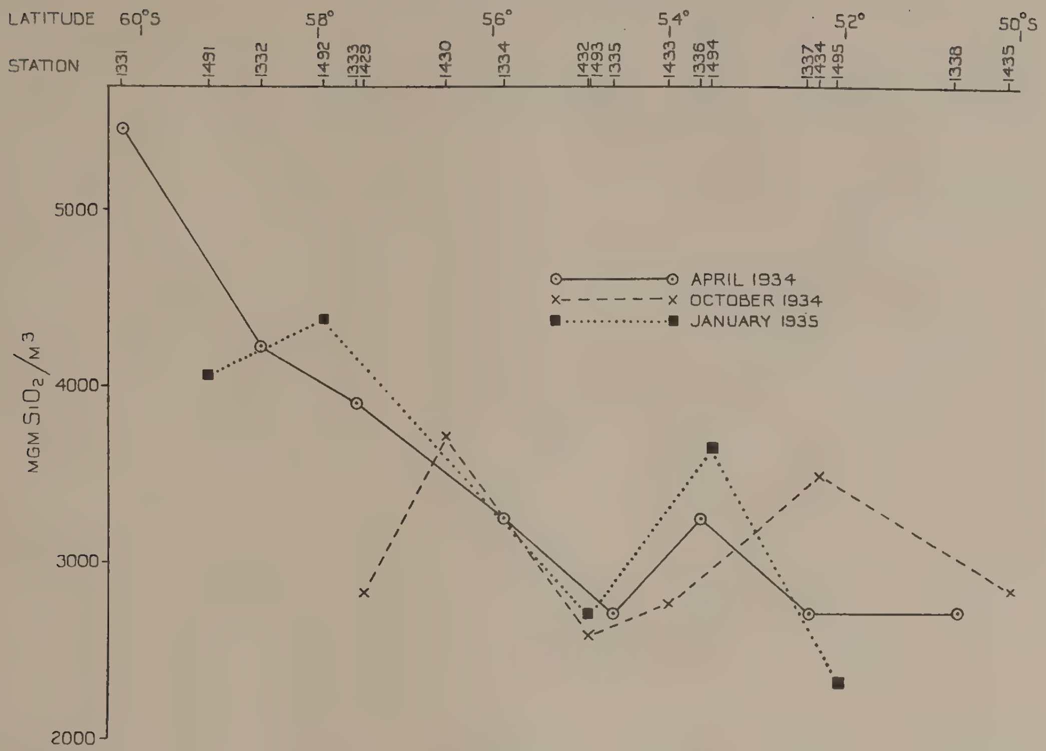

Fig. 23. Graph showing the variation of the silicate content from south to north at the depth of maximum temperature of the warm deep water in the Scotia Sea north of the South Orkney Islands.

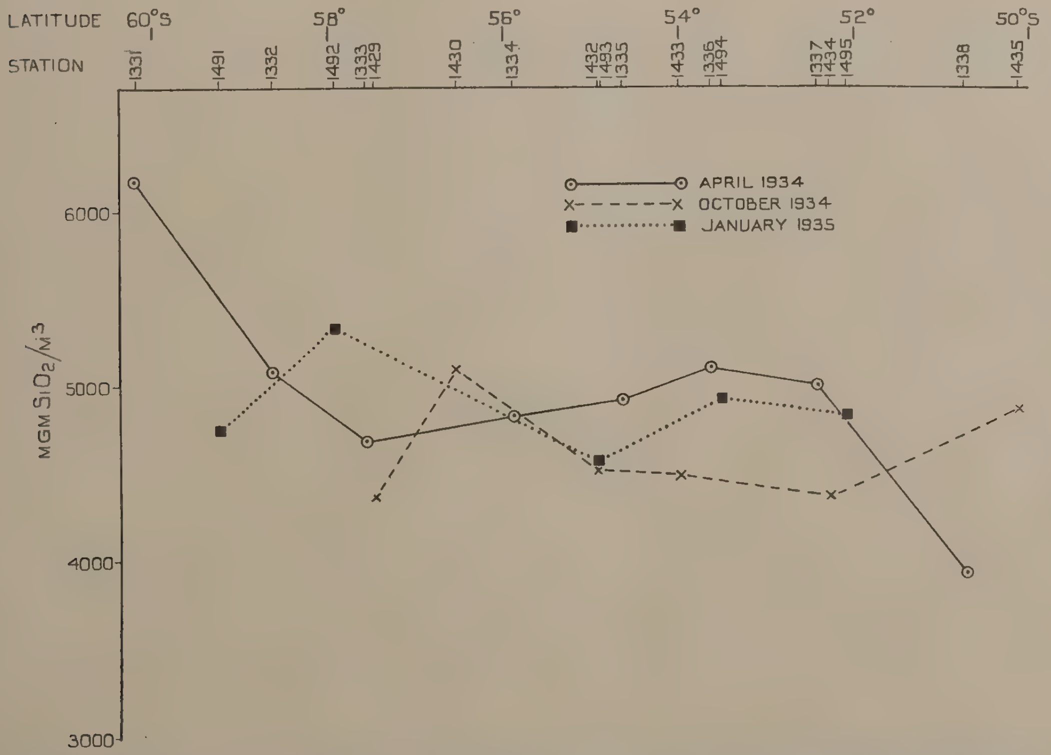

Fig. 24. Graph showing the variation of the silicate content from south to north at the depth of maximum salinity of the warm deep water in the Scotia Sea, north of the South Orkney Islands.

At the greater depth of the maximum salinity of the current, the content between 52° and 56½° S is greatest in April, less in January and least in October.

Around South Georgia the silicate content in the upper part of the current is about 3500 mg., and at the depth of maximum salinity it is about 4500 mg. The available data are scanty, and although some seasonal variation no doubt exists, no direct evidence of it has been obtained.

No data exist for the silicate content in the warm deep layer in the western part of the South Atlantic Ocean, but in April 1934 some observations were made between 53¾° and 61¼° S outside the Scotia arc just to the east of the South Sandwich Islands. Here the content in the upper part of the current was about 4100–4750 mg., and between 4650 mg. and 5350 mg. at the depth of the salinity maximum. The most southerly station in these observations was made in the cold eastward-flowing Weddell Sea water in which the maximum temperature of the warm deep water was only 0·44° C. The silicate content in this deep current was greater than at the more northerly stations and amounted to 5850 mg. in the upper layers and 6100 mg. at the depth of maximum salinity.

The silicate content of the warm deep water across the Southern Ocean in the Atlantic sector is summarized in Table VI, which represents observations made in February 1935 in a cruise from the south of the South Sandwich Islands to the ice-edge at the eastern entrance to the Weddell Sea and continued in a series of zigzags from and to the ice-edge as far east as 44° E. In general the silicate content south of 60° S decreased towards the east and north, the highest values being recorded across the Weddell Sea.

Table VI

Station	Date	Position	SiO_2 mg./m.^{3} of warm deep water	
			At max. t° C.	At max. S ‰
1510	10. ii. 35	59° 36·9′ S, 26° 57·7′ W	5975	6000
1511	11. ii. 35	61° 34·3′ S, 22° 46·3′ W	5800	6000
1513	12. ii. 35	63° 54·2′ S, 18° 21·2′ W	5900	6450
1515	13. ii. 35	66° 14·7′ S, 13° 50·2′ W	5050	5550
1517*	14. ii. 35	68° 44·7′ S, 09° 20·3′ W	5200	5300
1519	15. ii. 35	66° 31·0′ S, 03° 40·0′ W	4900	5300
1521	16. ii. 35	64° 34·5′ S, 00° 45·8′ E	4850	5150
1523	17. ii. 35	66° 39·2′ S, 05° 28·2′ E	5150	5250
1525*	18. ii. 35	68° 41·8′ S, 10° 34·8′ E	5250	5750
1527	19. ii. 35	66° 57·2′ S, 15° 10·3′ E	4800	5350
1529	20. ii. 35	64° 54·7′ S, 20° 00·6′ E	4250	4800
1531	21. ii. 35	62° 50·0′ S, 24° 28·2′ E	4150	5300
1533	22. ii. 35	65° 24·3′ S, 27° 07·8′ E	4900	5100
1535*	23. ii. 35	67° 18·0′ S, 30° 34·1′ E	4600	4950
1537	24. ii. 35	64° 33·6′ S, 33° 09·4′ E	4650	4900
1539	25. ii. 35	62° 02·1′ S, 35° 54·5′ E	4400	4400
1541	26. ii. 35	64° 26·6′ S, 39° 17·7′ E	4650	4650
1543*	27. ii. 35	66° 29·7′ S, 42° 26·0′ E	4450	4850
1545	28. ii. 35	64° 11·0′ S, 44° 05·1′ E	4300	4350

* Denotes an ice-edge station.

The silicate content of the warm deep water in the eastern part of the South Atlantic Ocean between 69° 20·8′ S and 3° 46·2′ N is shown in Plate VI. At the far south the warm deep water is flowing to the west, and the silicate content of this current both at the depths of maximum temperature and salinity was lower in March 1933 than that of the eastward-flowing water which had made the circuit of the Weddell Sea and which was encountered farther north in the same section. The westward-flowing deep water had a content of about 3700–3900 mg. in its upper layers and of about 4000 mg. at the depth of maximum salinity, whilst, as may be seen at St. 1158, the content at these same two positions in the eastward current from the Weddell Sea was 4950 mg. and 5000 mg. respectively. North of the cold Weddell Sea deep water the current is of North Atlantic origin and had a content of 4550 mg. at the depth of maximum salinity. North of this the content decreased until at 12½° S the value was 2250 mg.

In the course of some observations in April 1932 along section 5 between Cape Town and the ice-edge north of Enderby Land, which are shown in Plate IX, the existence of a large cyclonic circulation in the deep layers was shown. The section in Plate IX cuts across this circulation near its eastern end. Near South Africa where the deep water is flowing towards the east the silicate content at the depth of maximum salinity of the layer was 2550 mg. As the section progressed southwards the content at this position in the current increased until at Sts. 850 and 851 in 50° 43·8′ and 56° 22·1′ S respectively, where there are indications that the eastward-flowing warm deep water turns to the south and west, the content was about 4750–4950 mg. at the depth of maximum salinity; the higher value was recorded at St. 850, where the existence of a particularly active current eddy has been noted by Deacon (1937, p. 92) and active upwelling was in progress. In general the silicate content of the warm deep water increased southwards, and in 65° 15′ S, 48° 44′ E the content was 4650 mg. in the upper part of the current and 5850 mg. at the depth of maximum salinity.

A somewhat similar section (4) was made between the ice-edge in 42½° E and Cape Town in March 1935; the silicate distribution in this section is shown in Plate VIII. The section appears to lie east of the cold deep current which flows across the South Atlantic from the Weddell Sea. Towards the south the water is flowing westwards, whilst near Cape Town the movement is towards the east. The content in the upper layers of the current fell from an ice-edge value of 4450 mg. to 3250 mg. just south of the Antarctic convergence. Immediately to the north the content in the upper part of the current was 1200–1700 mg. At the greater depth of the salinity maximum the content fell northwards from an ice-edge value of 4850 mg. to one of 2850 mg. at the station nearest the coast of Africa.

A combination of observations made north of Enderby Land over the ridge between Marion Island and the Crozets in May 1934 with stations made between Marion Island and Guardafui in April–May 1935, gave a section (6) in the western part of the South Indian Ocean from 64½° S to 11½° N. The silicate distribution in these combined observations is shown in Plate XI. At the most southerly station where the warm deep water was colder and less saline and shows evidence of mixing, the silicate content was surprisingly low for the latitude; the values at the maximum temperature and salinity of the layer were 4250 mg. and 5200 mg. respectively. North of this station the content in the upper part of the current reached a value of 5050 mg. and then decreased to 3250 mg. south of the Antarctic convergence; at the deeper position of the salinity maximum it increased to 6100 mg. and then decreased to about 4000 mg. At the south of the sub-Antarctic zone the upper layers contained slightly less silicate but the content fell rapidly across the zone from 2900 mg. in the south to 1100 mg. just south of the subtropical convergence; the value at the depth of maximum salinity decreased northwards across the zone from 4100 mg. to 3500 mg. In the subtropical zone, where the warm deep water is mainly composed of North Atlantic Ocean deep water, the content at the depth of greatest salinity of the layer was about 3150–3300 mg. In the tropical zone where south of 20° S, the warm deep water is composed of North Atlantic deep water with a smaller proportion of North Indian Ocean deep water, the content was about 3000–3400 mg. at the salinity maximum. North of 20° S the warm deep current is composed of water of North Indian Ocean origin and is considerably closer to the surface. The maximum salinity of the layer rises from a depth of 1250 m. at 18½° S to 400 m. at 7° N, and the silicate content in this stratum of the current decreased from a value of 3200 mg. at 18½° S to 1550 mg. at 7° N. If this section be compared with section 3 in the eastern part of the South Atlantic Ocean (Plate VI) it will be seen that the North Indian Ocean deep water has a much greater silicate content than that of the North Atlantic deep water at corresponding latitudes; it was also found to have a higher phosphate content.

South of Australia between Cape Leeuwin and the ice-edge in 63° 41′ S, 130° 07′ E the warm deep water flows principally towards the east and south. Deacon (1937, p. 99) suggests that the eastward movement is strongest in the deep channel close to Cape Leeuwin, and along section 8 in May 1932 (Sts. 877–887, Plate XIII), the silicate content of the warm deep water was greater in this position than anywhere else in the section. In the subtropical region of the eastern part of the South Indian Ocean the deep water has a complex structure consisting of a mixture of North Indian deep water, Antarctic intermediate and bottom waters and North Atlantic deep water. The admixture of North Indian deep water and Antarctic bottom water would account for the high content of the deep water in the position noted above. From the deep channel near Cape Leeuwin the silicate content of the warm deep water at first dropped towards the south from a value of 5300 mg. at the depth of maximum salinity to one of 4450 mg. at the next station farther south. At the most southerly station in the sub-Antarctic zone the corresponding value was 4150 mg.; south of this, in the Antarctic zone, the content increased as the warm deep water became closer to the surface, so that at the ice-edge where the maximum salinity was found at 900 m. the corresponding silicate value was 5055 mg. The upper layers of the current in the Antarctic zone south of Australia had a content of about 3150 mg. in the north of the zone and 4300 mg. at the ice-edge.

In September 1932 section 12 was made from Wellington, New Zealand, to the ice-edge north of the Ross Sea in 62° 12·8′ S, 158° 11′ W; the section began in an area of irregular depth, and except for St. 944 in 47° 41·6′ S the depths were less than about

2500 m. until a latitude of 54° S was attained. South of 54° S the depth increased to about 5000 m. until the gradual rise to the Ross Sea began. The silicate content in this section is shown in Plate XVIII. At the deep station in 47° 41·6′ S the warm deep water had a content of 3150 mg. at the depth of maximum salinity. South of this latitude where the depth was great enough for the existence of warm deep water of a maximum salinity of 34·75 °/₀₀ in the north and of 34·72 °/₀₀ in the south, the silicate content at this depth increased slowly to 4300 mg. just north of the ice. At the actual ice-edge station the corresponding content was rather surprisingly low at 3550 mg., but the phosphate content was also considerably lower, giving the impression that the warm deep water had been mixed with water of a lower nutrient salt content. It is difficult to say what admixture had occurred, since the salinity of the layer had not been greatly affected and the maximum was 34·72 °/₀₀ compared with 34·73 °/₀₀ at the station immediately to the north. The content in the upper part of the current increased southwards from a value of 1400 mg. at St. 949 just north of the Antarctic convergence to 3150 mg. at the ice-edge.

In a somewhat similar section (13) in January 1934 from the ice-edge in 69° 49·4′ S, north of the Ross Sea, to Auckland, New Zealand, shown in Plate XX, the warm deep water contained much more silicate than in September 1932. Thus at the ice-edge in January the upper layers of the current contained 4650 mg., while at the depth of maximum salinity the content was 5000 mg., these amounts decreasing northwards, particularly in the upper part of the current. Since the two sections were made at different seasons of the year the latitude of the ice-edge was very different. In September 1932 the ice-edge was as far north as 62° 12·8′ S. The following table gives a comparison with a January station near this position:

Station	Date	Position	SiO_2 mg./m.^{3} of warm deep water	
			At max. t° C.	At max. S °/₀₀
956	9. ix. 1932	62° 12·8′ S, 158° 11·0′ W	3150	3530
1273	20. i. 1934	62° 08·1′ S, 168° 59·5′ W	3700	5050

The increased amount of silicate in the observations of January 1934 was continued throughout the section, and at St. 1281, which was situated closest to New Zealand, the content at the depth of the lowest observation, at 2500 m., was as great as 5300 mg. The difference between the amounts in the two years cannot be explained at present; in the absence of more knowledge of the seasonal and annual variations in the constitution of the warm deep water in this part of the ocean, no definite conclusion can be reached. It is obvious, however, that something of the nature of a seasonal or an annual variation does exist, since the maximum salinity of the warm deep water near New Zealand was 34·75 °/₀₀ in September 1932 and 34·78 °/₀₀ in January 1934; this difference of 0·03 °/₀₀ is a very significant one in such a deep layer.

In the South Pacific Ocean, owing to the low latitude attained by the subtropical convergence the majority of our observations are in the Antarctic zone and the southern part of the sub-Antarctic zone. In September 1932 a W-shaped cruise (sections 12, 14, 15 and 16) was made in the South Pacific consisting of four sections, one of which, from Wellington to the ice-edge in 61° 07′ S, 153° 57·2′ W, has already been discussed. The other sections were from the ice-edge north of the Ross Sea in a north-east direction to a point 41° 03′ S, 126° 04′ W in the central part of the ocean, from there in a south-east direction to 63° 57′ S, 101° 16′ W and then north-eastwards to the western entrance to the Magellan Strait. At the ice-edge north of the Ross Sea the silicate contents at the depths of maximum temperature and salinity were 3850 mg. and 4500 mg. and they decreased towards the north-east until just north of the Antarctic convergence the corresponding values were 1200 mg. and 3600 mg. In the sub-Antarctic zone the depth of the current was greater, so that in the south the depth of maximum salinity was found at about 2500 m. and at the most northerly station at 4000 m. The silicate content at the depth of maximum salinity increased from 2750 mg. just south of the convergence to a value of 3600 mg. in the south of the sub-Antarctic zone and 4300 mg. at the most northerly station.

From the mid-South Pacific station in 41° 03′ S, 126° 04′ W the silicate content at the depth of maximum salinity in the sub-Antarctic zone at first increased south-eastwards from a value of 4300 mg. to one of 5500 mg., and then, just north of the Antarctic convergence, dropped to 4050 mg. The section did not quite reach the ice-edge, but in 63° 57′ S the content at the salinity maximum was 4550 mg. From 63° 57′ S the content decreased north-eastwards to 3550 mg. just south of the Antarctic convergence, but north of this boundary it increased again to 4100 mg. in 55° 18·4′ S, 80° 08·1′ W.

In 1934 a considerable number of observations were made along the ice-edge region in this ocean in the months of January, February and March in the course of two cruises: a westward cruise from 80° W to the eastern entrance to the Ross Sea and a return eastward cruise from 171½° to 80° W. The return journey was made at a slightly higher latitude owing to the retreat of the ice during the interval between the cruises; altogether thirty-two deep stations were made. In the course of the westward cruise, except for the extreme eastern stations where the upper part of the warm deep water contained 4000–4300 mg., the silicate content in this part of the current increased from east to west, being about 3000–3300 mg. in the east and 4600–4700 mg. in the west. Similarly the content at the depth of maximum salinity increased westwards from values about 3500–4000 mg. in the east to 5000–5300 mg. in the west, the extreme eastern part of the ocean being again excepted. The depth of the warm deep current also changed from east to west; the upper layers were found at 600–800 m. in the east, about 400 m. in the central part of the ocean and about 300 m. in the west, the maximum temperature of the layer falling from about 2° C. in the east to 1·4° C. in the west. Similarly, the depth of the salinity maximum of the layer changed, being about 1000–1500 m. in the east and about 500–600 m. in the west.

On the return eastward cruise, except for stations in the extreme east, the silicate content of the warm deep water fell in a corresponding manner from west to east both in the upper layers and at the depth of maximum salinity. The depth of the current increased from west to east and the maximum temperature in the upper part of the layer increased from 1·40° to 1·90° C. in the same direction. During the course of the cruise the silicate content fell from 4700 mg. to 3500 mg. in the upper layers and from 5100 mg. to 4500 mg. at the greater depth of the salinity maximum. The contents at the two positions in the current during both cruises are shown in Fig. 25. The fact that the silicate content of the warm deep water in this part of the ocean is less in the east than in the west must be due to the fact that the general direction of movement of the current is towards the east and south. The increase in temperature of the current towards the east suggests that the eastward current of warm deep water from the region south of Australia must be joined by warm deep water from the north and such water would have a lower silicate content. During the eastward movement, mixing must occur at the upper and lower boundaries, and since the neighbouring water masses are poorer in silica the content of the current will decrease from west to east.

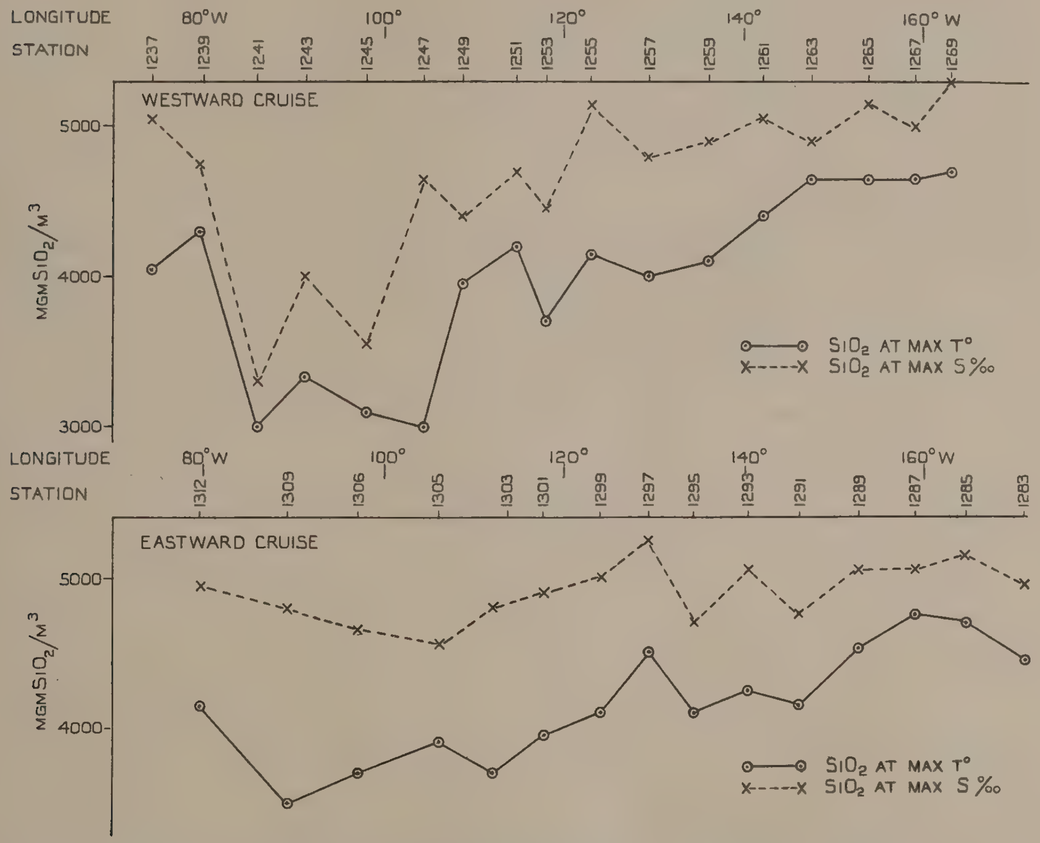

Fig. 25. Graph showing the silicate content at the depths of maximum temperature and salinity of the warm deep water in the ice-edge region of the South Pacific Ocean in January–March 1934.

In 80° W five sets of observations have been made from the ice-edge northwards in December 1933, March, September, October and November 1934, but on no occasion were observations made north of 55° S. The latitude of the ice-edge varied very considerably, being farthest south in March and farthest north in September. In the upper layers of the warm deep water the silicate content decreased northwards from values of approximately 4500 mg. in 68° S, in summer and early autumn, and of 3250 mg. in 64° S, in winter, to about 1500–2500 mg. in 58–59° S in the sub-Antarctic zone. In the neighbourhood of the Antarctic convergence practically no variation occurred except for the month of November when the content was higher. At the depth of maximum salinity the content was about 5000 mg. at the southern end of the line of stations and about 4500–5000 mg. at 56° S. As the diagrams in Figs. 26 and 27 show, there is insufficient evidence for a discussion of seasonal variation.

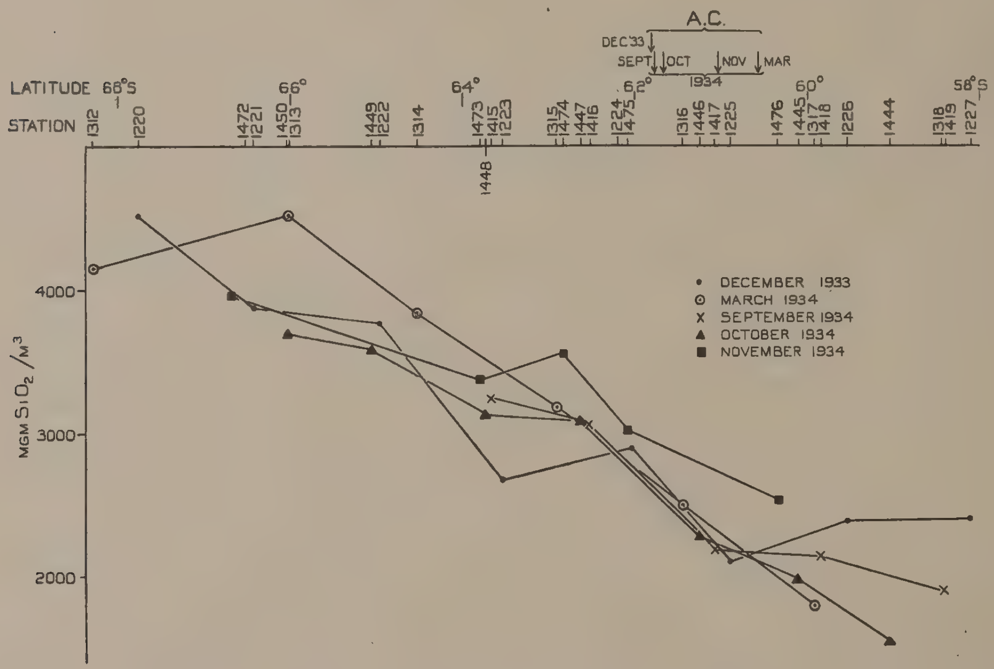

Fig. 26. Graph showing the variation of the silicate content from south to north at the depth of maximum temperature of the warm deep water in 80° W.

The silicate content in the upper part of the warm deep water has been discussed by reference to the content at the depth of maximum temperature of the layer, chiefly in the Antarctic zone; that at a greater depth is given by the content at the depth of the salinity maximum of the current.

In the Scotia Sea the content in the upper part of the current varied from 5500 mg. to 2700 mg. from south to north, whilst around South Georgia values of 3500 mg. and 4500 mg. are recorded for the upper and lower portions of the current. Warm deep water which has made the circuit of the Weddell Sea has a very high content. Observations south of 60° S in the Atlantic sector of the Southern Ocean showed that the content decreased towards the east and north.

In the eastern part of the South Atlantic Ocean between 69½° S and 3¾° N the content in the current increased from the ice-edge (3700–3900 mg. in the upper part and 4000 mg. at the depth of maximum salinity) to 4950 mg. and 5000 mg. in the eastward-flowing Weddell Sea deep water. North of this latter current the content decreased until at 12½° S the content at the salinity maximum was 2250 mg.

South of Cape Town the content increased southwards, and in the upper part of the current values of 1200–1700 mg. were recorded at the Antarctic convergence, with 4450 mg. at the ice-edge. At the deeper position of the salinity maximum the increase southwards was from 2850 mg. to 4850 mg. at the ice-edge. Higher values were, however, found in 1932 in this area.

In the western part of the South Indian Ocean the upper part of the current had a content of 4250–5050 mg. in the south and 3250 mg. at the Antarctic convergence, the content falling northwards across the sub-Antarctic zone from 2900 mg. to 1100 mg. At the deeper position in the current the decrease northwards from the ice-edge to the subtropical convergence was from 5200–6100 mg. to 3500 mg. In the subtropical zone the warm deep water is mainly of North Atlantic origin, and the content at the salinity maximum was 3150–3300 mg. North of 20° S in the tropical zone the warm deep water is of North Indian Ocean origin, and although a decrease was observed northwards, the actual content of North Indian deep water was shown to be greater than of North Atlantic deep water at the same latitude; this higher silicate content of the North Indian deep water may be correlated with the fact that the phosphate content of Indian deep water is higher.

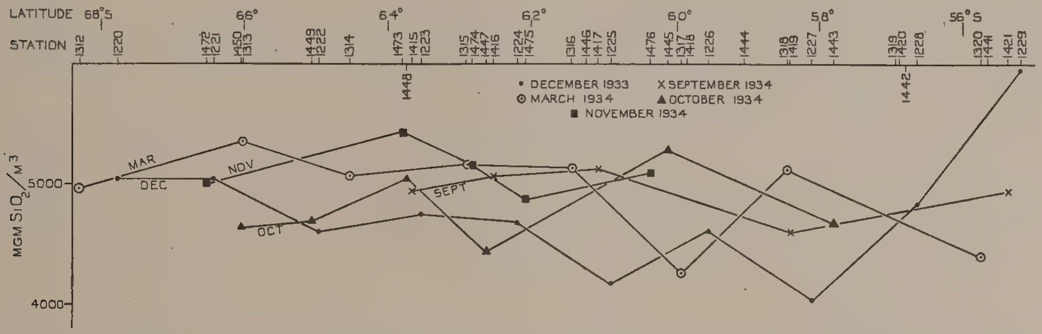

Fig. 27. Graph showing the variation of the silicate content from south to north at the depth of maximum salinity of the warm deep water in 80° W.

At the ice-edge south of Australia the content in the upper part of the deep layer was 4300 mg., a value which decreased towards the north across the Antarctic zone to 3150 mg. At the depth of maximum salinity an ice-edge value was 5055 mg., the content falling towards the north. In the deep channel near Cape Leeuwin a higher content was noted.

South-east of New Zealand the content of the warm deep water was shown to be subject to annual or seasonal variation. Much more silicate was present in 1934 than in 1932. The following table shows this:

September 1932		
SiO_2 at maximum salinity	3150 (47° 41·6′ S)	4300 (3550 at ice-edge)
,, ,, ,, t° C.	1400 (just north of Antarctic convergence)	3150 (at ice-edge)
January 1934		
SiO_2 at maximum salinity	4750 (47° 16·5′ S)	5000 (at ice-edge)
,, ,, ,, t° C.	1450 (just north of Antarctic convergence)	4650 (at ice-edge)

In the central part of the South Pacific the content decreased northwards across the Antarctic zone from values of 3850 mg. and 4500 mg. at the depths of maximum temperature and salinity to values of 1200 mg. and 3600 mg. respectively just north of the Antarctic convergence. The current was at a greater depth in the sub-Antarctic zone and the silicate content increased.

In the ice-edge region of the South Pacific, except in the extreme east, the silicate content of the warm deep water increased from east to west from 3000–3300 mg. in the east to 4600–4700 mg. in the west in the upper part of the current, and from 3500–4000 mg. in the east to 5000–5300 mg. in the west at the deeper position of the salinity maximum. This increase in silicate content is connected with the general direction of movement of the current which is towards the east and south. Also the increased temperature from west to east in the current indicates that the deep water in its passage from west to east is mixing with other waters and loses silicate in so doing.

In 80° W five sets of observations in different months showed that the silicate content in the upper part of the warm deep water decreased from south to north across the Antarctic zone. The content at the ice-edge ranged from 4500 mg. in 68° S, in March, to 3250 mg. in 64° S, in September. There was a further fall to 1500–2500 mg. in 58°–59° S. Approximately 5000 mg. were present at the ice-edge at the depth of maximum salinity, a content which decreased slightly northwards.

ANTARCTIC BOTTOM WATER

PHOSPHATE AND SILICATE CONTENT

There is no sharp density discontinuity between the warm deep water and the colder bottom water. Evidence for the existence of these two currents is of course supplied by longitudinal sections of temperature, salinity and oxygen content in the South Atlantic, Indian and Pacific Oceans. The phosphate content of the bottom water may best be seen from the sections in the plates at the end of this report. It is not possible to give charts of horizontal distribution in this layer because at present our data are inadequate to make allowances for seasonal or annual variation, i.e. although we have data from a good number of stations the observations from any one month are not sufficient to enable charts to be drawn. Antarctic bottom water which was formed in winter will have a greater nutrient salt content than that formed in summer.

The phosphate content of the Antarctic bottom water is always large but with the exceptions mentioned on p. 81 the content is always less than that of the warm deep water.

In the Drake Passage along section 1 (Plate III), the bottom water had a content of the order of 135 mg. in April 1930. In the Scotia Sea values of 160 mg. were recorded in April 1934, and of 140 mg. in September and October 1934 and in January 1935. The bottom water around South Georgia in September 1934 had a content of about 150 mg. compared with 135 mg. in February 1935.

In April 1931 in the Antarctic zone in the western part of the South Atlantic Ocean (section 2, Plate IV), the bottom water had a phosphate content of between 125 mg. and 145 mg., the content being greater towards the south. In the sub-Antarctic zone the content was found to be about 140–150 mg., whilst at 38° S a value of 156 mg. was recorded at the lowest observation which was made in mixed warm deep and bottom waters. North of 38° S the West Atlantic basin is narrowed by a westward extension of the mid-Atlantic ridge. This ridge cuts off the direct passage of bottom water to the north in our section, and the lowest observations on the actual ridge, made within 100–200 m. of the bottom, show that the warm deep water at this depth has a low phosphate content. North of this ridge where the depth of the ocean is about 5000 m. the general content of the bottom water was about 85–95 mg. with one isolated value of 117 mg. at a depth of 4900 m. at 21° 13′ S.

In March-April 1933 along section 3 in the eastern half of the South Atlantic Ocean (Plate V), the bottom water in the Antarctic zone had a phosphate content of about 100–105 mg.; there was little variation from the ice-edge in 69° 20·8′ S as far north as 41° S where the content at the deepest observation, some 240 m. from the bottom, was 136 mg. The position of this station was north of the Atlantic-Indian cross-ridge which acts as a partial barrier in the east to the northward flow of Antarctic bottom water; the bottom water found north of this ridge has become mixed with warmer water which usually has a lower content. The latitude of 41° S is the position in which maximum phosphate was recorded throughout the section; a value of 157 mg. was found at a depth of 1000 m. in the Antarctic intermediate water. It is probable that the maximum decomposition of the Antarctic plankton occurs here, and perhaps the debris which rains down to the bottom undergoes further decomposition to enrich the bottom water in this position. It is a striking fact that nowhere else throughout the entire section between 69° 20·8′ S and 12° 29·8′ S does the phosphate content of the bottom water approach a value of 136 mg. North of this position the phosphate content decreased considerably. It must not, however, be forgotten that the nutrient salt content of the bottom water varies and the high value found at 41° S may be to the production at some previous time of bottom water with a high content. Thus in the eastern part of the South Atlantic Ocean a considerable variation in nutrient salt content occurs in the Antarctic zone. The following observations are typical examples.

Station	Position	Date	Depth (m.)	t° C.	S °/₀₀	P_2O_5 mg./m.^{3}	SiO_2 mg./m.^{3}
1154	69° 20·8′ S, 09° 33·8′ E	12. iii. 1933	2000	−0·01	34·68	108	5300
1525	68° 41·8′ S, 10° 34·8′ E	18. ii. 1935	2000	0·02	34·67	132	6250
1158	58° 37·5′ S, 14° 42·7′ E	16. iii. 1933	4000	−0·45	34·66	101	5200
1355	58° 43·3′ S, 16° 38·1′ E	2. v. 1934	4000	−0·42	34·67	160	7200

In late April and early May 1934 between the South Sandwich Islands and 44° E an average value at twelve positions for the phosphate content of the Antarctic bottom water of a temperature of 0·0° C. was 148 mg., whilst in the same area in February 1935 the average figure for nineteen stations was 138 mg.

In May 1934 along section 6 from the ice-edge in 44° E northwards to the Crozets (Plate X), an average phosphate content of the bottom water of 0·0° C. and 34·67–34·68 °/₀₀ was about 160 mg. in the south of the Antarctic zone and about 140 mg. just south of the Crozets ridge. North of this ridge the character and composition of the bottom water is considerably changed, being more saline and warmer and containing much less phosphate. Plate VII shows the phosphate content of Antarctic bottom water along section 4 in late February and early March 1935. The phosphate content of bottom water of temperature 0° C. and salinity 34·67–34·68 °/₀₀ was 140 mg.

During the circumpolar cruise of 1932 the Southern Ocean was crossed diagonally along section 7 between the ice-edge in 65° 15′ S, 48° 43·7′ E to Fremantle, Australia. The phosphate section is shown in Plate XII. At the far south Antarctic bottom water of 0° C. and salinity 34·66–34·67 °/₀₀ had a content of about 110 mg. Farther along the section, towards the western side of the Kerguelen-Gaussberg ridge, the content increased to about 125 mg., an increase which continued across the ridge.

The phosphate content along section 9 south of Australia in late May 1932 is shown in Plate XIV. The bottom water had a phosphate content of 130–135 mg. in the Antarctic zone. North of the Antarctic convergence the content decreased to about 120–125 mg., but here the bottom water was mixed with a large proportion of warm deep water. At the southern end of section 10 from Melbourne to the ice-edge in 61° 25′ S, 154° 26′ E (Plate XV) the bottom water had a phosphate content of 134 mg., whereas at the deep stations near Macquarie Island the contents were 121 mg. and 110 mg. respectively. Deacon (1937, p. 114) has drawn attention to the fact that the bottom water only finds its way into the deep basins south of New Zealand after being substantially mixed with warm deep water: near Macquarie Island the relatively large increase of temperature and decrease of oxygen and phosphate contents of the bottom water are accompanied by only a small increase of salinity, and it seems as if the mixing with warm deep water has taken place in a region where the salinity of the deep water has been reduced almost to that of the bottom water by turbulent mixing which would have the effect of reducing the phosphate content of the mixed bottom water found near Macquarie Island.

The bottom water found in September 1932 along section 12 in the deep basin south-east of New Zealand (Plate XVII), shows by its high temperature and salinity that it is a very mixed water. At the northern station in this basin (47½° S) the bottom water at 4500 m. had a phosphate content of 92 mg. Farther south there is a rise in the sea bottom, and south of this rise the values at 4500 m. were 79 mg., 71 mg. and then, in the southern part of the basin, 123 mg. It is difficult to see from what mixture of waters this water of low phosphate content in the north of the basin is derived, because south of the basin the phosphate content rose to 161 mg. at 3000 m. on the Cape Adare-Easter Island ridge in 61½° S with very little difference in temperature and in salinity. Unfortunately section 13 made in 1934 from the Ross Sea to New Zealand (Plate XIX) cannot be used to check the 1932 results owing to the fact that no observations were made below 3500 m. in the critical position.

Section 14 in 1932 from the ice-edge north of the Ross Sea to a position of 41° 03′ S, 126° 04′ W in the central part of the South Pacific crossed the Cape Adare-Easter Island ridge; the phosphate distribution is shown in Plate XXI. On the western side of the ridge, where the bottom current is turned to the north, the bottom water had a content of about 135–145 mg. On the eastern side of the ridge, between 150° and 140° W, the bottom water once more bends to the south and had a content of 145 mg.

The remainder of the South Pacific Ocean cruise of 1932 along sections 15 and 16 (Plates XXIII and XXV) showed that the bottom water in the Antarctic zone between 110° and 100° W at a depth of 5000 m. had a phosphate content of about 135–140 mg.; this had decreased to 120 mg. at 94° W. Between 80° and 90° W in the southern part of the sub-Antarctic zone the content at a depth of 4500–5000 m. increased northwards from 122 mg. just north of the Antarctic convergence to 136 mg. in 55° 18·4′ S.

In 1934 a considerable number of observations were made in the region of the pack-ice in the South Pacific sector of the Southern Ocean. These showed quite clearly that the bottom water had an eastward component of movement across the ocean. It increased in temperature and decreased in oxygen content in its passage across the ocean, showing that it mixes with warm deep water during this movement. The phosphate content at 4000 m. in the bottom water varied irregularly. On the cruise towards the west the extreme range was 122–148 mg., but in general it varied from 135 mg. to 145 mg., increasing slightly towards the east. On the return cruise towards the east higher contents were encountered as the following figures show:

	Westward cruise	Eastward cruise
Date	1–18. i. 1934	23. ii–10. iii. 1934
Number of observations	16	15
Average latitude	67° 23′ S	68° 56′ S
Average P_2O_5 in mg./m.^{3} at 4000 m.	136	152

Although the eastward cruise was made at a slightly higher average latitude owing to the retreat of the ice in the interval between the cruises, the difference in phosphate content in the bottom water must be due to another cause which at present we must assume to be seasonal variation. It may be added that in November of the same year nine stations situated between 80° and 110° W and within a short distance of the ice-edge, gave an average content of 142 mg. at a depth of 4000 m., so that a seasonal variation is fairly evident. Similarly a variation existed in the routine line of observations in 80° W. Thus, average values in 1934 at 3500 m. between the ice-edge and about 55° S were as follows: March 157 mg., September 131 mg., October 140 mg., November 139 mg. Fig. 28 gives the phosphate content at the deepest observations in 80° W, the depth of the samples being at least 3500 m. It will be remembered that the bottom water of the Scotia Sea had a phosphate content of 160 mg. in April 1934 compared with a content of 140 mg. in September and October of the same year. If we compare these values with those along 80° W in 1934 some evidence may be deduced for a penetration of Scotia Sea bottom water through the Drake Passage into the eastern part of the South Pacific but at present the evidence from other sources, i.e. oxygen content, suggests that only a trace of Scotia Sea bottom water may penetrate westward.

The phosphate content of Antarctic bottom water is always large but is usually less than that of the warm deep water. Seasonal variation occurs and in the Scotia Sea in 1934 the content varied between 140 mg. and 160 mg.

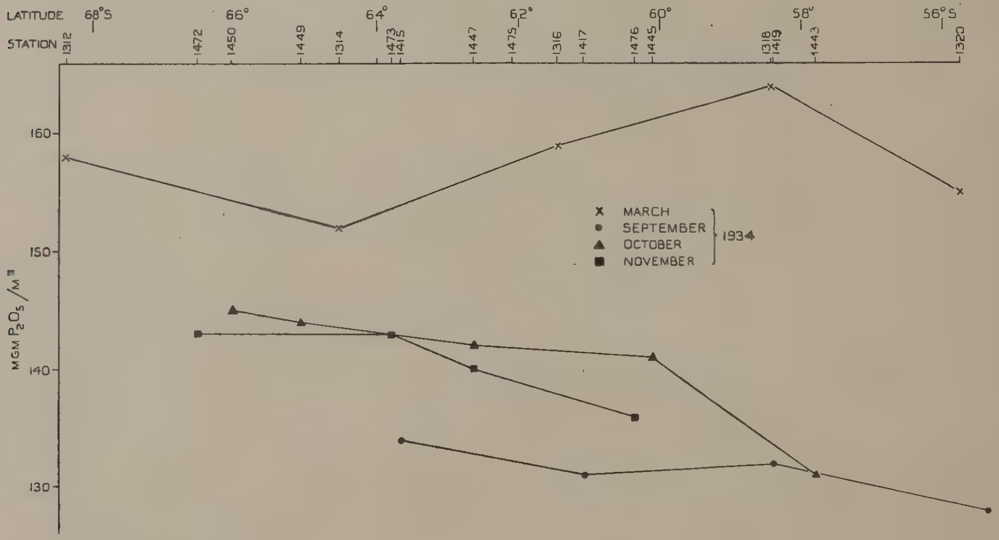

Fig. 28. Graph showing the variation of the phosphate content from south to north at the deepest observation (3500 m. or deeper) in 80° W.

In 30° W Antarctic bottom water had a content of 145 mg. in the south and 125 mg. in the north of the Antarctic zone. Sub-Antarctic zone values were 140–150 mg., whilst at 38° S a high content of 156 mg. was recorded in mixed bottom water.

In 1933 very low contents were recorded for the bottom water in the eastern part of the South Atlantic where only 100–105 mg. was found in the Antarctic zone, whilst in 1934 and 1935 considerably higher values of 130–160 mg. were found.

South of the western part of the South Indian Ocean the Antarctic bottom water had in 1934 a content of 160 mg. decreasing to 140 mg. in the north of the Antarctic zone.

In 1935 an average value in the same area was 140 mg. It is evident that the very considerable seasonal and annual variation in phosphate content which occur render the charting of phosphate content at any given position in the bottom water impossible until more data is at hand to make allowances for these changes.

Across the Southern Ocean between Enderby Land and western Australia the content was 110 mg., increasing on the Kerguelen-Gaussberg ridge to 125 mg.

South of Australia the bottom water in the Antarctic zone had a content of 130–135 mg. which decreased north of the convergence, whilst in the deep stations south of the Tasman Sea, near Macquarie Island, the bottom water had been subjected to mixing and had a content of 110–121 mg.

South-east of New Zealand in the deep basin in 50–60° S the bottom water had a low content of 71–79 mg. in the north and 123 mg. in the south, whilst on the Cape Adare-Easter Island ridge the content was as much as 161 mg. In the central part of the South Pacific, in the neighbourhood of the Cape Adare-Easter Island ridge, the content was 135–145 mg., this was a general content throughout the remainder of the Antarctic zone as far as 94° W where the value was 120 mg. In the sub-Antarctic zone between 80° and 90° W the content increased northwards from 122 mg. to 136 mg. in $55\frac{1}{4}$° S.

A number of observations in 1934 in the pack-ice region of the South Pacific showed evidence of seasonal variation in the content of the bottom water at 4000 m. A westerly cruise gave an average of 136 mg., whilst an easterly one gave an average value of 152 mg. some five weeks later. Similarly in 80° W in the same year a seasonal variation was evident.

The silicate content of Antarctic bottom water is always large, particularly in the Antarctic zone. At a depth of 4000 m. a usual content of the bottom water in the Antarctic zone is about 6000–7000 mg., but values greater than 7000 mg. have been found, notably in December 1933 when as much as 8600 mg. was recorded in the Scotia Sea and over 8000 mg. at the ice-edge in 78° W, both at a depth of 3500 m. When the rain of silica skeletons from the very large concentrations of diatoms which flourish in the Antarctic surface water is considered, it is clear that the Antarctic bottom water must be the seat of a large amount of silicate; the diatom skeletons which form the diatom ooze are in contact with the bottom water and re-solution must occur continuously, whilst fresh supplies of dead diatoms are deposited after the time of phytoplankton efflorescence in the spring and summer months.

In general the Antarctic bottom water in the Southern Ocean flows east and north. Wüst (1933) showed that the Antarctic bottom water could be traced as far north as 40° N in the western Atlantic. As a result of the northward movement large quantities of silicate are carried away from the Antarctic zone but they are replenished by the southward movement of the warm deep water. Mixing between the bottom and deep currents transfers silicate to the latter current.

In the Antarctic zone the silicate content is not always a maximum at the bottom.

During the third commission of the R.R.S. 'Discovery II' some 120 stations were made in the Antarctic zone at positions where the depth was greater than 3000 m. At seventy of these stations there was most silicate at the depth of the lowest observation, usually less than 500 m. from the bottom. At fifty stations the silicate content was greater above the lowest observation, and at forty-four of these fifty stations the maximum content occurred at depths between 500 and 1500 m. above the lowest observation. Thus in the Antarctic zone during 1933–5 the silicate content of the bottom water was always large and at seven out of twelve stations in this zone the actual maximum occurred at depths less than 500 m. from the bottom, whilst at the other five out of twelve maximum silicate occurred at a higher level in the bottom water.

In the light of our present knowledge the geographic areas where the silicate content decreases near the bottom lie chiefly in the Antarctic zone south of the Atlantic Ocean, and south of the Pacific Ocean between 130° and 140° W. The temperature range at the seat of the maximum in these areas is −0·31° to 0·31° C. south of the Atlantic and 0·12–0·32° C. in the area 130–140° W. The reason why silicate is not always most abundant near the bottom has not been ascertained.

In the Scotia Sea a few extremely high values of 8000–8600 mg. were recorded in December 1933, but a greater number of observations, in 1934–5, showed that the usual content was not so high. The following figures give the silicate content from south to north at the depth of the lowest observation which was at least 3000 m.

	Silicate mg./m.^{3} at deepest observation	
	North	South
March–April	6000	6500–7000
September–October	5400	6000–6500
January	5500–5700	5500–5700

The silicate content of the Antarctic bottom water along section 3 in the eastern part of the South Atlantic Ocean in March 1933 is shown by the vertical section in Plate VI. At the ice-edge the content at the deepest observation was 5300 mg., and there was little change as far north as the Atlantic-Indian cross-ridge which rises in our section to a saddle depth of 2633 m. in about 51½° S. This ridge impedes the northward flow of bottom water which, however, passes into the Agulhas basin by a gap found to the east of the section. North of the cross-ridge the silicate content of the bottom water which is now a mixed water, falls steadily towards the north. In March 1935 the silicate content of the bottom water in the Agulhas basin was 6000 mg. in the south and 4000 mg. on the northern side. This compares well with previous observations in April 1932 of 6000–6500 mg. in the south and 4300 mg. to the north.

In the Atlantic-Antarctic basin a large number of observations were made in April–May 1934 and February–March 1935, and at the great majority of stations the content at the lowest observation, usually less than 500 m. from the bottom, was lower than that of a higher level in the Antarctic bottom water. The difference varied from station to station and ranged from 50 to 1700 mg. In general the content of the bottom water in this area varied from 5500 to 7500 mg. being greater at the more northerly stations in the basin, and less at the ice-edge stations. There are some indications of a cyclonic circulation of the bottom water, with an easterly movement towards the north of the basin and a southerly movement at approximately 30° E. A considerable variation in silicate content of the bottom water exists in this basin, particularly in the eastern part where in May 1934 (section 6, Plate XI) silicate of the order of 7500 mg. was found in the bottom water of 0° C. whilst in February-March 1935 only 5500–6000 mg. was recorded (section 4, Plate VIII).

In May 1932 the deepest observations in the Antarctic zone (section 8, Plate XIII) south of Australia, had a silicate content of 6000–6500 mg. which slowly decreased north of the convergence. In the south Australian basin where the bottom water is clearly mixed with a considerable amount of warm deep water from the Atlantic and Indian Oceans the bottom water had a content of 5400 mg.

Two sets of observations south-east of New Zealand are shown in Plates XVIII and XX. In 1932 (Plate XVIII) the content of the bottom water was between 4500 mg. and 5000 mg. at the deepest observations at the southern end of the section as compared with over 6000 mg. in a comparable latitude in 1934 (Plate XX). Actually more than 7000 mg. was recorded in 67½° S in 1934 at a depth of 2500 m. The bottom water south-east of New Zealand consists of a mixture of the eastward flowing bottom water from the Weddell Sea and warm deep water of mixed origin. The fact that the silicate contents of the bottom water were so different in the two years must be due to the seasonal and probable annual variations in the constituent waters. In 1932 at the deep stations south of the shallow water near New Zealand, the silicate content increased continuously with depth in the bottom current to values of 4200–4400 mg. at a depth of 4500 m. In 1934 the observations did not extend below 3500 m., at which depth the content was of the order of 5300 mg.

In September 1932 from the ice-edge north of the Ross Sea to 41° 03′ S, 126° 04′ W in the central part of the South Pacific (section 14, Plate XXII), the Antarctic bottom water between 160° and 130° W was warmer and more saline than it was north of the Ross Sea; it also advanced more towards the north. Deacon (1937, p. 115) has shown that this advance was not caused by an increase in the current due to sinking of shelf water, but is rather due to the influence of the Cape Adare-Easter Island ridge which causes the bottom current to bend towards the north in the shallower water between 160° and 150° W and to bend back towards the south between 150° and 140° W on the other side in the deeper water. The silicate content of the bottom water in this section shows that on the actual ridge, which is about 3000 m. from the surface, there was about 4500–5500 mg. at a depth of 2500 m., whilst in the deeper water between 150° and 140° W there was a content of 4300 mg. at a depth of 4500 m.

The remainder of the 1932 cruise across the South Pacific (Plates XXIV and XXV), showed that in the deep stations in both the Antarctic and the southern part of the sub-Antarctic zones the bottom water had a content of the order of 5000 mg.

In 1933–4 a large number of stations were made near the pack-ice in the South Pacific, and also on a routine section in 80° W. In the course of a cruise from 1 to 18 January from 74° to 160° W at an average latitude of 67° 23′ S, the silicate content of Antarctic bottom water at sixteen stations averaged 6475 mg. at a depth of 4000 m. On the return journey at a slightly higher average latitude of 68° 56′ S from 171½° to 80° W the average content at a depth of 4000 m. at fifteen stations was about 6600 mg. In November of the same year ten stations at an average latitude of 64° S between 80° and 110° W averaged a silicate content of 6100 mg. at 4500 m. The above data are not sufficient to show the seasonal variation but give the approximate amount of the silicate content. Future investigation is likely to show a periodic variation in the nutrient salt content of the bottom water in this region as is indicated by Fig. 29. From this figure, which gives the silicate content at the deepest observations in 80° W northwards from the ice-edge, it seems that at the south end of the sections the silicate content of the bottom water was greatest in December and lowest in September and October, the difference being very considerable. At the latitude of the Antarctic convergence no great seasonal change is shown, but at the northern end of the sections some variation occurred, the December results again being greatest and those of October least.

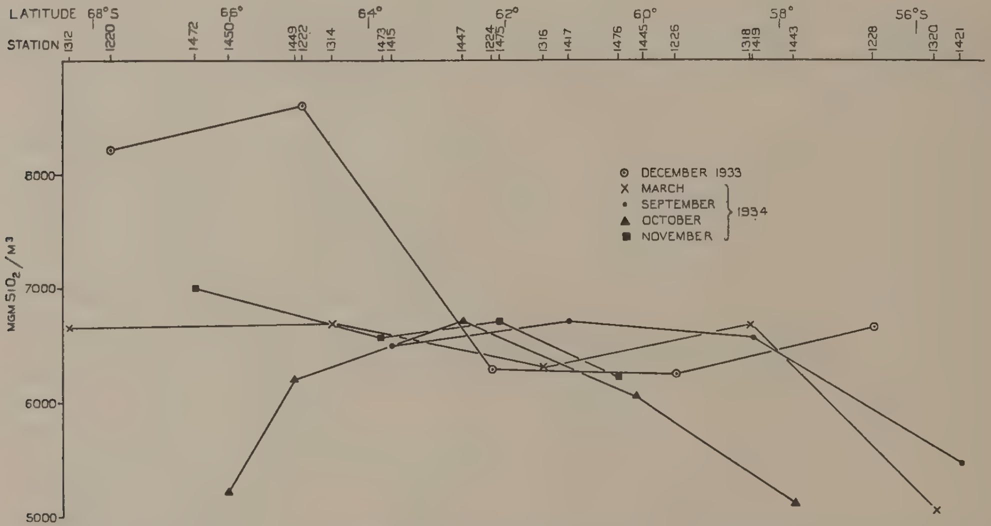

Fig. 29. Graph showing the variation of the silicate content from south to north at the deepest observation (3500 m. or deeper) in 80° W.

As a summary of the present data on the silicate content in the Antarctic bottom water it may be said that silicate is found in large quantity in this current particularly in the Antarctic zone where as much as 8600 mg. has been recorded; a more usual content is, however, 6000–7000 mg.

On account of the northerly component in the movement of this current large quantities of silicate are removed from the Antarctic zone and are returned in the lower layers of the warm deep water.

The highest concentrations of silicate are found in the Antarctic zone, either at the lowest observation, usually less than 500 m. from the bottom, or else at a higher level in the bottom current.

The silicate results from the bottom water of the Atlantic-Antarctic basin supply some evidence for the existence of a cyclonic circulation in this current in this area. The content of silicate in the bottom water appears to vary periodically, and this was specially noticeable in two sections south-east of New Zealand and in the section in 80° W.

THE REGENERATION OF PHOSPHATE AND SILICATE

As we have seen, the concentration of phytoplankton near the Antarctic convergence suddenly increases enormously each spring and almost as quickly falls again under the onslaught of the increasing concentration of zooplankton and also because of possible limiting factors. The enormous increase of phytoplankton in spring is made at the expense of the nutrient salts. Perhaps some idea of the very large concentrations of both phytoplankton and nutrient salts in the Antarctic may be gathered from the following figures for the average content of the 0–50 m. layer. For the sake of comparison, values from the English Channel have also been added.

Locality	Pre-outburst average value in 0–50 m. layer		Average concentration of phytoplankton in 0–50 m. layer during main outburst expressed as arbitrary colour units
	P_2O_5	SiO_2	
South Georgia	125	2000	27,660
English Channel	27	325	2,970*

* Average at L. 4 in March 1933 and 1934.

Even at the far south of the Antarctic zone the average value of the density of the phytoplankton throughout the period from the beginning of the third week in December to the end of the first week in March is nearly as great as that at the spring maximum in the English Channel where the outburst lasts for approximately six weeks only.

The huge amounts of phytoplankton found in the Antarctic are responsible for the withdrawal from the photosynthetic zone of the surface layer of correspondingly large amounts of nutrient salts, as the following data from St. 1529 in 64° 54·7′ S, 20° 00·6′ E conclusively show.

Depth (m.)	0	10	20	30	40	50	60	80	100
P_2O_5 mg./m.^{3}	68	64	64	65	112	120	124	124	124
SiO_2 mg./m.^{3}	750	750	850	900	2150	2250	2500	2800	3000

The data in the above table are typical of a position where the concentration of phytoplankton is high. In winter the 0–100 m. layer at such a station becomes completely mixed; the result is a homogeneous layer and the phosphate and silicate contents are equally distributed so that a pre-outburst value of the surface phosphate is probably 125 mg. and 3000 mg. for silicate. Thus at St. 1529 in February 1935 as much as 75 per cent of the available silicate and nearly 50 per cent of the available phosphate had been withdrawn from the 0–30 m. layer by the large concentration of phytoplankton. It does not follow that the above proportions of the concentrations of the available nutrient salts are always withdrawn by the main outburst of phytoplankton, nor is the amount utilized in this way the same throughout the Antarctic. All plankton workers who have experienced Antarctic conditions are agreed upon the "patchiness" of the plankton. there, and this unevenness must be reflected in the nutrient salt contents. As an example, data are given in the following table from two stations some miles apart, but in the same hydrological region and made within a day of one another:

St. 1269, 67° 33·8′ S, 162° 53·7′ W, 18 January 1934

Depth (m.)	0	10	20	30	40	50	60	80	100
P_2O_5 mg./m.^{3}	61	63	59	58	65	70	95	117	117
SiO_2 mg./m.^{3}	2250	2250	2450	2450	2500	2400	3250	3500	3400

St. 1271, 65° 05′ S, 166° 08·4′ W, 19 January 1934

Depth (m.)	0	10	20	30	40	50	60	80	100
P_2O_5 mg./m.^{3}	112	112	112	111	112	113	118	124	129
SiO_2 mg./m.^{3}	3200	3150	3150	3200	3250	3300	3550	3450	3900

The density of the phytoplankton in the 0–50 m. layer was between 12 and 13 times as great at St. 1269 as at St. 1271.

As we have seen earlier in this report phosphate and silicate leave the Antarctic in the form of plankton, or in the northward flowing Antarctic surface and bottom currents. These nutrient salts must be returned to the Antarctic zone mainly in the warm deep water but the whole account of the regeneration is much more complicated than this statement might suggest. During the time of the main outburst of phytoplankton in the Antarctic zone, not only are the Antarctic surface and bottom waters carrying away large concentrations of plankton and nutrient salts but mortality of phytoplankton from a number of causes including consumption by the zooplankton is also taking place. The consequence is that a rain of debris consisting of dead diatoms, foraminifera, radiolaria, cast skins of crustaceans and excretions by the zooplankton takes place. Not all the water masses in the Antarctic zone have a northerly component of movement; for instance, the warm deep water presses southwards and carries with it any debris that happens to be in or pass into this layer. Later the debris may pass into the Antarctic bottom water which has a northerly movement. The existence of the belt of diatom ooze near the Antarctic convergence is clear evidence of the rain of dead diatoms. When the phytoplankton ceases to be a living entity and the individuals sink or are excreted, regeneration of the nutrient salts is possible. The actual method of regeneration is imperfectly understood but presumably it must be aided by bacterial action in the sea-water or in the digestive system of the zooplankton. The importance of the rain of dead plankton on the regeneration of nutrient salts may be seen in the high phosphate and silicate contents of the Antarctic bottom water. Also, in the sub-Antarctic zone, the subsurface current has a higher nutrient salt content than the surface current; whereas it should have a lower content judging by its method of formation and by its constituent water masses which consist of sub-Antarctic surface water (which sinks at the subtropical convergence) and subtropical water. If there were no rain of dead plankton which decomposes and regenerates nutrient salts, the subsurface water would undoubtedly have lower contents than the surface water.

Thus nutrient salts are carried out of the Antarctic zone either free or contained in dead and living plankton which decomposes in deeper layers in one part of the nutrient salt cycle; but also decomposition and regeneration in situ occur within the antarctic and other zones. The decomposition and regeneration within the Antarctic zone are complicated by the fact that the locality of the maximum concentration of phytoplankton changes throughout the season. Thus at the Antarctic convergence and immediately south of it the maximum concentration of phytoplankton occurs in November–December, but as the season progresses the loss of nutrient salts by the position of the maximum density of phytoplankton moves southwards so that in late February maximum concentration is found near the ice-edge. Thus as the season progresses the northward movement of the plankton is lessened because the position of the maximum is farther south and hence there is more chance for, say the diatoms, to sink and decompose and regenerate silicate in the Antarctic zone, whereas in the earlier part of the season the diatoms tend to be swept out of this zone, to decompose at the convergence or north of it. In the western and eastern parts of the South Atlantic Ocean vertical sections of phosphate content (Plates IV and V) show that maximum regeneration occurs in the region 38–43° S in the western part of the ocean and at 41° S in the eastern part. This is obviously the result of decomposition of plankton carried out of the Antarctic zone by the surface current which sinks at the Antarctic convergence.

As an example of regeneration in situ some observations at St. 1543 in 66° 29·7′ S, 42° 26′ E may be cited. This station was made in late February 1935 on the ice-edge north of Enderby Land. Dr Hart, who has examined the phytoplankton catches at this station, tells me that there is strong evidence that the volume of phytoplankton present, though of a moderately high concentration, is but a shadow of its former density and that adjacent stations a little to the west and on the same latitude had much greater concentrations. The phytoplankton catches contained a high proportion of euphausian faeces consisting of diatom remains. Thus the phytoplankton conditions at this station were ideal for regeneration *in situ*. The table on p. 108 gives some of the relevant physical and chemical data.

As may be seen from the low temperature at 200 m. the surface layer is a thick one for this latitude and contains two well-marked discontinuity layers, one between 10 and 20 m. and the other, the normal division between the surface and warm deep currents, between 200 and 300 m. The upper discontinuity has been formed in the absence of rough weather by an accumulation of thaw water. This layer has given rise to ideal conditions for the growth of a large concentration of phytoplankton and in this connection it is noteworthy that the silicate value at 10 m. is less than that at the surface. Had a sample been taken at 5 m. I think it more than possible that the silicate content there would have been even less. From the phosphate distribution in the upper part of the surface layer it is clear that phytoplankton production has been restricted to the 0–20 m. layer, whilst the character of the phytoplankton catches proves that mortality due to consumption by zooplankton has taken place, i.e. the zooplankton has excreted the undigested siliceous skeletons of the diatoms. Below a depth of 20 m. the phosphate content of the surface layer is as high as 128 mg. which indicates that either decomposition of the dead phytoplankton has taken place with instant regeneration of the phosphate or else that no phosphate has been consumed, i.e. the pre-outburst phosphate content was 128 mg. in the surface layer and the outburst was confined to the 0–20 m. layer. The latter supposition is far more likely to be the correct one since the zooplankton requires some of this phosphate for its own growth, whilst the undigested siliceous skeletons and other unwanted bodies are excreted. Some recent research work at Plymouth (Harvey, Cooper, Lebour and Russell, 1935) is of great interest in this connection. These workers found that in the English Channel, only a fraction of the phosphate utilized by the phytoplankton during the first half of the year was found as phosphorus compounds in the zooplankton. They consider that much of the organic phosphorus compounds such as phosphoproteins and phospholipins in diatoms may pass undigested through animals and remain in solution in the sea until regeneration to phosphate by the aid of bacterial action takes place after an interval of three to four months. Obviously some future research into the seasonal variation in the nutrient salt content of southern plankton combined with similar data of the sea-water in the photosynthetic zone would be of very great interest and some attempt will be made to this end in a subsequent cruise of the 'Discovery II'.

Depth (m.)	t° C.	S ‰	σt	O_2 c.c./litre	P_2O_5 mg./m.^{3}	SiO_2 mg./m.^{3}
0	−1·46	32·98	26·55	7·86	72	2700
10	−1·50	32·98	26·55	—	73	2500
20	−1·68	33·55	27·02	7·16	102	2850
30	−1·72	33·91	27·31	—	128	3100
40	−1·74	34·20	27·55	6·30	128	3250
50	−1·76	34·25	27·59	—	128	3250
60	−1·77	34·29	27·62	6·18	128	3150
80	−1·78	34·33	27·65	—	128	3400
100	−1·81	34·33	27·66	6·25	129	2900
150	−1·80	34·34	27·67	6·56	128	2450
200	−1·66	34·37	27·68	6·56	128	2450
300	0·72	34·65	27·80	4·52	128	4100

The silicate and oxygen content data at St. 1543 seem to be very instructive in showing that regeneration of silicate is taking place in situ mainly as a result of a rain of dead diatoms and faecal pellets from the surface. Thus the oxygen content at the surface is 7·86 c.c./litre. Below the surface the oxygen content falls at least as far as 60 m. with a probable minimum at 80 m. The silicate content is 2500 mg. at 10 m., below which it increases to a maximum for the Antarctic surface layer of 3400 mg. at 80 m. It will be noticed that at 150 and 200 m., in the bottom of the Antarctic surface layer, the oxygen content has increased and the silicate decreased. The definite increase in oxygen content at 150 and 200 m., together with the lowered silicate content would seem to indicate that the water in the layer between 150 and 200 m. represents water which has sunk to these depths from the surface sometime previously. It must be admitted, however, that the phosphate content of 128 mg. at these depths does not agree with this conclusion unless silicate is selectively absorbed by the phytoplankton before the phosphate. Silicate is obviously being regenerated between 20 and 100 m. with a maximum at 80 m., this regeneration being accompanied by a fall in oxygen content as might be expected. When the observations were made this regeneration had not progressed so far at depths below 100 m., as the results at 150 and 200 m. undoubtedly show. In this respect it is significant that the euphausian faecal pellets were chiefly in the upper part of the surface layer.

Thus the results at St. 1543 afford an excellent example of regeneration of silicate in situ. Although the actual methods of decomposition and regeneration are not known, the fact that a large number of siliceous skeletons had obviously passed through the digestive system of the zooplankton tends to suggest that perhaps the siliceous skeletons are excreted in such a condition that re-solution is facilitated. Obviously a knowledge of the *p*H of the digestive system of the zooplankton would be of service in this connection. It is possible that silicate from the excreted faecal pellets of the zooplankton is directly dissolved in the reasonably high *p*H of the upper part of the surface water and that this may explain the very rapid regeneration of silicate that appears to take place.

It has been noted (Earland, 1936, p. 8) that in bottom samples from the Weddell Sea, diatoms are almost entirely absent whereas farther north diatom skeletons form the diatom ooze. Of course the concentration of diatoms in the Weddell Sea is less than that in the northern region. It is possible that the diatom ooze is formed by those diatoms whose mortality is due to some cause other than their being eaten by zooplankton, i.e. the belt of diatom ooze is found south of or close to the Antarctic convergence, where a sudden change of temperature occurs and where the sinking surface water may cause a high mortality of diatoms which sink and are not redissolved as fast as they are deposited. It is also possible that the operation of a limiting factor in the densely populated surface water in the northern region of the Antarctic zone may be responsible for a high mortality and the formation of the belt of diatom ooze.

The suggestion has been made earlier in this report that when the zooplankton consumes the phytoplankton part of the phosphate content of the latter is incorporated in the former, whilst the siliceous skeletons of the diatoms and other undigested parts of the phytoplankton are excreted. If this suggestion be correct, it follows that regeneration of phosphate from the faeces of the zooplankton in situ is likely to be smaller than that of silicate which appears to be very rapid, as the evidence at St. 1543 indicates. It must be emphasized that the above statement is strictly confined to regeneration in situ from faecal remains of zooplankton and does not include decomposition and regeneration of nutrient salts from dead zooplankton. Cooper (1935, p. 200) added samples of animal and plant plankton to sea-water in glass vessels and found that the breakdown of the zooplankton was very rapid and that more phosphate was set free than had originally been added as plankton. The balance was produced from dissolved organic phosphorus compounds in the sea water. The breakdown of phytoplankton showed a short time lag and only a part of the added phosphorus was set free as phosphate.

In support of the argument that the zooplankton retains part of the phosphate and rejects the siliceous skeletons of the phytoplankton, it will be noted that vertical sections of phosphate and silicate contents in the Southern Ocean and north of it differ very considerably. Thus in the South Atlantic Ocean for example, phosphate is at a maximum in the region 38–43° S whereas silicate is always maximal in the Antarctic zone. The phosphate maximum occurs north of the Antarctic convergence because plankton is carried out of the Antarctic zone into the Antarctic intermediate current, and in this current maximum decomposition and regeneration of phosphate occur in the above latitudes. On the other hand the maximum concentrations and the greatest mortality of phytoplankton occur within the Antarctic zone or close to the Antarctic convergence, with the consequence that maximum silicate is found in this zone. The statement that maximum regeneration of phosphate in the South Atlantic Ocean occurs in the regions 38–43° S in the west and 41° S in the east is supported by the fact that the phosphate content of the bottom water is maximal in these regions (Plates IV and V); this tends to suggest that decomposition occurs in two stages, one of which takes place in the Antarctic intermediate current and the other in the great depths of the bottom water. The former is undoubtedly the seat of the greater regeneration but the phosphate regenerated in the bottom water must travel farther north before it completes the phosphate cycle by being transferred by mixing to the bottom of the south-going warm deep water.

In view of the possible application of the results obtained from such an enclosed area as the English Channel to the open sea, it is interesting to note that Cooper (1933, pp. 741–4) found that the minimum production of plankton calculated from chemical data of changes in the contents of carbon dioxide, oxygen, phosphate, nitrate and silicate in the English Channel agreed very well amongst themselves with the single exception of silicate. Cooper suggested that silicate seemed to go through the life cycle of plankton several times in one season. This work (*loc. cit.* p. 697 and also part III) strongly suggests that regeneration of silica can proceed rapidly at the surface and near the bottom in a depth of 70 m.

The surface area of most plankton diatom skeletons is large compared with the volume of the individual and offers a good opportunity of re-solution in sea water of moderately high *p*H such as is found in Antarctic waters. It has been noted by Stanbury (1931) that skeletons of dead diatoms disappear rapidly in culture experiments.

Solution of silicate occurs not only from dead diatom skeletons; Bachrach and Lefèvre (1928, 1929) have observed the complete loss of the external skeletons from a number of living plants reared on sterilized media even in the presence of silicate. The removal of the siliceous skeleton may require weeks or only a few days. The defective diatoms appear to live and reproduce quite normally although after a few generations they become so shapeless that identification is impossible. Cooper (*loc. cit.* p. 697) quotes the above work to show the rapidity with which the skeletons may dissolve in sea water and the possible adaptability to silicate shortage of diatoms leading an otherwise normal life. Dr Hart assures me that in the northern region of the Antarctic zone the diatoms tend to develop less strongly silicified frustules immediately after the main outburst of the phytoplankton.

Thus the regeneration of silicate within the Antarctic zone appears to take place quite rapidly from the rain of dead diatoms or of diatom skeletons excreted in situ Phosphate also regenerates in situ but at a much slower rate; the evidence of vertical sections shows that it is regenerated also in quite a large degree by the decomposition of plankton outside the Antarctic zone. Although to the best of my knowledge no instance has been recorded amongst the Discovery data of masses of dead zooplankton being caught inside the Antarctic zone, I think it most likely that not all the zooplankton passes out of the zone, nor is it all consumed by fish, whales, etc. Thus it is probable that an unknown proportion of Antarctic zooplankton may die within the Antarctic zone and be decomposed there to return nutrient salts to the water masses present. When the smaller animals in the zooplankton are consumed by the larger individuals large quantities of phosphorus-containing products of digestive action will be liberated to the sea water and later will produce phosphate available for the phytoplankton. The excretion of faecal pellets from all the plankton will be another source of phosphorus-containing material.

On occasions it has been noted that the plankton hauls contained quantities of the cast off shells of crustaceans; this casting off of shells takes place often, particularly when the crustacean is growing quickly. It would be expected that cast shells of calcified species of crustaceans would enrich the surrounding sea water with calcium phosphate. If this is correct a direct return of phosphate *in situ* will occur.

PHOSPHATE AND SILICATE CONCENTRATION AS POSSIBLE FACTORS LIMITING PLANKTON PRODUCTION

In spring and summer the change in concentration of phytoplankton in the Antarctic zone is particularly rapid just south of the Antarctic convergence and less so in the arbitrarily defined regions to the south. Such a change must be brought about by a change in one or both of two opposing factors, the rate of growth of phytoplankton (depending on illumination and probably the concentration of nutrient salts) and the rate at which the phytoplankton is eaten (dependent on the number and kind of herbivorous animals). Here we are concerned with the effect of the nutrient salt concentration.

Data from various parts of the Antarctic zone in 1933–5 have been included in Table VII so that the extent of the withdrawal of nutrient salts by phytoplankton may be seen. These stations have been selected from a large number of observations as examples of large withdrawals of nutrient salts. It must be remembered that particularly in the arbitrarily defined northern region of the Antarctic zone the duration of the main outburst of phytoplankton is fairly short, and consequently the amount of data obtained at these times is bound to be relatively small. Table VII represents a fair number of the appropriate data. From this table it is clear that the phosphate content in the photosynthetic zone of the Antarctic surface layer is never[1] reduced to less than about 55 mg. $P_2O_5/m.^3$ The winter maximum of the English Channel may reach 40 mg., and during the spring outburst of phytoplankton this is almost entirely withdrawn from the surface. The Antarctic phytoplankton is of course very much richer than that of the English Channel but even so, there still remains after the main outburst more phosphate in the Antarctic surface water than is present before the spring outburst in the English Channel. Thus it may be reasonably assumed that lack of phosphate is not likely to be a limiting factor for the growth of phytoplankton in Antarctic water unless Antarctic phytoplankton requires a higher minimum initial amount than does northern temperate phytoplankton.

On the other hand, the withdrawal of silicate from the upper layers of the Antarctic surface water during the phytoplankton outburst is enormous. St. 1198 was situated almost at the northern boundary of the Antarctic zone in the South Atlantic Ocean and was taken in late November which is probably the time of maximum production for this position. The actual phytoplankton density in the 0–50 m. layer expressed as arbitrary colour units was 15,940 with which may be contrasted the spring maximum of the English Channel which is of the order of 2970. As may be seen from Table VII silicate was completely withdrawn from the 0–50 m. layer at St. 1198. In the Antarctic zone of the western part of the South Pacific Ocean the silicate content was less than 200 mg. in January 1934, whilst in the Scotia Sea and eastwards across the south Atlantic Ocean in January and February 1935 the silicate was reduced to the order of 500–700 mg. from a pre-outburst value of 3000–3500 mg. During the South Georgia survey in November 1933 surface values of silicate content ranged from <400 mg. to 1000 mg. at a time just after the maximum concentration of phytoplankton. Possibly had the observations been made a little earlier at South Georgia we might have found the silicate completely removed from the upper part of the surface layer. In the Scotia Sea between the South Orkney Islands and the Antarctic convergence our present evidence shows that a minimum withdrawal of 50 per cent of the available silicate occurs during the phytoplankton season at the southern end of the sea and approaching 80 per cent in the north.

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[1] Since the above was written R.R.S. 'Discovery II' has been investigating the nutrient salt content of the surface water north of Prince Olaf harbour at South Georgia at a time when the concentration of phytoplankton was very high. In these circumstances it was found that the surface content of phosphate and silicate had been reduced to values of about 28–33 mg. and 130–180 mg. respectively. These values are very much lower than have hitherto been recorded near South Georgia especially for phosphate. The observations were made in a localized patch where production had been extremely high and this may account for the very low values of the nutrient salts.

The withdrawal of such a high proportion of available silicate must have a large effect on the growth of phytoplankton, and silicate paucity is possibly a limiting factor at one stage of the phytoplankton season. The more recent work of the last commission of R.R.S. 'Discovery II' has shown that the surface silicate may be reduced to 130–180 mg. in an area near South Georgia where the concentration of phytoplankton was enormous. If silicate then be possibly a limiting factor, the continued growth of phytoplankton is checked at a time when the number of herbivorous zooplankton is increasing at a very high rate. Harvey, Cooper, Lebour and Russell (1935, pp. 407–42) have shown that

Table VII

Station	Date	Position	0 m.	10 m.	20 m.	30 m.	40 m.	50 m.	100 m.
1198	25. xi. 1933	50° 51·9′ S, 31° 25·6′ W	95	92	91	89	97	95	105
			0	0	0	0	0	0	350
1234	29. xii. 1933	58° 12·6′ S, 62° 21·5′ W	82	81	82	87	89	89	93
			450	550	550	650	800	650	1050
1273	20. i. 1934	62° 08·1′ S, 168° 59·5′ W	59	56	54	57	111	125	129
			<200	<200	<200	<200	950	1600	2175
1275	21. i. 1934	59° 29·2′ S, 170° 01·8′ W	89	90	84	86	90	85	111
			<200	<200	<200	<200	<200	<200	1000
1285	24. ii. 1934	68° 45′ S, 164° 35·8′ W	80	80	80	82	85	122	129
			2450	2500	2550	2700	2650	3050	3700
1289	25. ii. 1934	69° 08′ S, 152° 42·4′ W	70	70	70	70	71	124	117
			1750	1600	1600	1750	1700	2350	2800
1309	8. iii. 1934	67° 45·9′ S, 89° 23·5′ W	86	88	87	95	97	124	136
			550	800	850	950	1050	1650	2450
1316	12. iii. 1934	61° 27·1′ S, 78° 58·8′ W	116	115	114	114	114	115	134
			<300	<300	<300	<300	<300	<300	1150
1337	7. iv. 1934	52° 25·1′ S, 44° 09·6′ W	113	111	110	107	110	114	146
			350	400	400	450	550	600	1050
1344	22. iv. 1934	53° 46·3′ S, 24° 57·4′ W	76	72	72	73	74	77	99
			<300	<300	<300	<300	<300	<300	1250
1491	23. i. 1935	59° 15·7′ S, 43° 36·4′ W	73	73	73	75	76	77	137
			650	650	700	700	800	750	3350
1492	23. i. 1935	57° 56·2′ S, 43° 48·5′ W	71	72	72	72	73	72	134
			650	650	650	700	700	800	3500
1501	5. ii. 1935	52° 43·7′ S, 36° 57·9′ W	76	76	76	76	78	79	100
			500	500	500	500	500	550	2300
1502	5. ii. 1935	53° 03·6′ S, 36° 58·5′ W	68	68	68	68	68	70	100
			450	400	400	425	400	400	1750
1529	20. ii. 1935	64° 54·7′ S, 20° 00·6′ E	68	64	64	65	112	120	124
			750	750	850	900	2150	2250	3000
1543	27. ii. 1935	66° 29·7′ S, 42° 26·0′ E	72	73	102	128	128	128	129
			2700	2500	2850	3100	3250	3250	2900

The upper line at each station in the table represents the phosphate content in mg. $P_2O_5/m.^3$ at the various depths, whilst the second line represents the corresponding silicate data in mg. $SiO_2/m.^3$

in the English Channel the number of faecal pellets found in a plankton sample bears a distinct relation to the amount of plant food available. These workers draw the conclusion that the amount of plant food eaten depends rather on the amount of food available than on the dietary requirements of the animal population. If therefore a rapidly increasing zooplankton concentration consumes phytoplankton to such a large degree it is obvious that any checking in the growth rate of phytoplankton by a limitation of an essential nutrient salt will exert a large influence on the amount of phytoplankton available at that time. During summer in the Antarctic both phyto- and zooplankton are present in enormous concentrations but it is significant that the highest concentration of zooplankton occurs after the maximum concentration of phytoplankton.

As further evidence of the effect of a limitation in the amount of silicate available Dr Hart tells me that the robust, spiny phase of *Corethron criophilum* (which is a dominant species in the early part of the phytoplankton season in the Antarctic zone) tends to change over in late summer to the spineless chain form with very thin, fragile walls. Also, Dinoflagellates tend to become important in the extreme northern part of the northern region of the Antarctic only in February and these organisms probably contain less silicate than equivalent quantities of diatoms.

Although silicate is considered to be quickly returned to the sea water, phosphate on the other hand is held for some considerable time as organically combined phosphorus compounds and as such is unavailable for the needs of phytoplankton growth. Thus when phytoplankton is consumed and a very rapid regeneration of silicate takes place, the growth rate of phytoplankton is not visibly increased as far as our experience holds. In this sense then phosphate may possibly be limiting and when the required interval for the breakdown of organically combined phosphorus has taken place, then some other factor such as illumination may prevent a large subsequent outburst of phytoplankton in the autumn. In this connection it may be added that some slight evidence does exist for a small secondary autumnal outburst of phytoplankton in the south.

Because, at the majority of Antarctic stations the amounts of phosphate and silicate found in the surface layer never fall below the amounts present in winter in the English Channel, it is possible that factors other than limitation of phosphate or silicate must be invoked to explain the sudden falling off of the huge concentrations of phytoplankton in the Antarctic. Dr Hart (1934, pp. 183–193) has reviewed many such factors and the reader is referred to this work for a full account. Dr Hart considers both chemical and physical factors but thinks physical factors exert the strongest influences upon phytoplankton production in the far south—such factors being the influences due to weather, currents (including turbulence), light, ice conditions and temperature.

SUMMARY

This report is based on the measurements of phosphate and silicate in the Southern Ocean made by the Discovery Committee's scientific staff between 1929 and 1935; it describes the cycles by which phosphate and silicate are removed from the Antarctic by the northward-flowing surface and bottom currents and returned in the southward-flowing deep current, and it gives an account of the concentrations and fluctuations of phosphate and silicate in the surface, deep and bottom currents.

Phosphate leaves the Antarctic as free phosphate or as organically combined phosphorus, and, in the surface current, combined in the plankton. After the surface current sinks at the Antarctic convergence it becomes enriched by decomposition of plankton, and in the South Atlantic Ocean, for example, the greatest concentrations of phosphate are found between 38° S and 43° S in the west, and in 41½° S in the east. A large proportion of this phosphate is transferred to the upper part of the southward-flowing deep current by vertical mixing; before the deep current is enriched in this way it is relatively poor in phosphate. The North Indian deep current is an exception, being itself rich in phosphate. The lower part of the deep current also returns phosphate to the South—taking it from the Antarctic bottom current.

An examination of all the data available suggests that when the rich phytoplankton of the Antarctic is consumed by the zooplankton, most of the silica is excreted while much of the phosphorus is retained and not returned to the sea until the plankton decomposes. As a result, the greatest concentrations of silica are found where the greatest concentrations and mortality of diatoms occur—in the Antarctic zone, and the greatest concentrations of phosphate where the decomposition of the zooplankton is greatest—between the Antarctic intermediate current and the warm deep current in the sub-Antarctic zone. The maximum phosphate content is generally about 160 mg. $P_2O_5/m.^3$

Silicate is most abundant in the Antarctic bottom current. Although it is regenerated to a large extent in the surface layer, there is a rain of debris including dead diatoms, foraminifera, radiolaria, cast skins of crustacea and zooplankton faeces, into the bottom current. A silica content as much as 8600 mg. $SiO_2/m.^3$ has been observed, but a maximum of 6000–8000 mg. is more usual. A large proportion of the silica that is carried northwards by the bottom current is transferred by vertical mixing to the lower part of the deep current; the smaller quantities carried northwards in the Antarctic intermediate current enrich the upper part of the deep current.

South of the Antarctic convergence the warm deep current has generally a higher phosphate content than the surface and bottom currents. Observations repeated in the same localities show that the content can alter appreciably in a short time, and it is believed that such changes are related to those which occur in the water that sinks at the Antarctic convergence: at the season when the sinking surface water is rich in decomposing plankton more phosphate will be transferred to the deep current, and a rich patch will be produced in the deep current.

The phosphate and silicate concentrations at the level of minimum salinity in the Antarctic intermediate current do not decrease regularly towards the North, and there are regions of maximum phosphate and silicate which coincide with regions of maximum salinity and minimum oxygen; there are also phosphate and silicate minima which coincide with salinity minima and oxygen maxima. It is considered that these variations are related to the seasonal changes in the Antarctic surface layer and that they may serve as a basis for an approximate estimation of the rate of the northward movement of the intermediate current.

To help in the analysis of the data from the Antarctic surface layer three areas, distinguished by Dr T. J. Hart from the type of phytoplankton communities they support, have been examined. A southern region extending 200 miles north of the ice-edge, a northern region extending 300 miles south of the Antarctic convergence, and an intermediate region are described. In winter the surface phosphate ranges from about 125–130 mg. $P_2O_5/m.^3$ near the ice-edge to 110 mg. near the convergence; the summer range is 80–85 mg. to 75 mg. Smaller concentrations have been observed due to dense local outbursts of phytoplankton, but it is thought that such conditions do not last long and that the average content is soon restored.

The winter silicate content of the Antarctic surface water at the ice-edge ranges from 3000–3500 mg. $SiO_2/m.^3$ in the Atlantic Ocean to about 2000 mg. in the eastern part of the Pacific Ocean; the figures for the northern part of the zone are about half these values. In summer the surface content in the Atlantic Ocean is reduced to 500–1000 mg. near the ice-edge, and to a lower figure, sometimes to zero, in the northern part of the zone. Several factors—date and extent of diatom outburst, currents and mixing—make an accurate summary impossible.

In the sub-Antarctic zone the winter surface phosphate content ranges from 100–110 mg. $P_2O_5/m.^3$ in the south to about 70 mg. in the north, and in summer the corresponding range is 60–70 mg. to 30–40 mg. The surface silicate content ranges from about 700 mg. $SiO_2/m.^3$ to 200 mg. in winter, and from 0–300 mg. to 0–200 mg. in summer.

In the southern part of the subtropical zone phosphate ranges from 30 mg. $P_2O_5/m.^3$ in winter to 5–10 mg. in summer, and silicate from 410 mg. $SiO_2/m.^3$ to less than 250 mg.

In the Antarctic zone lack of phosphate is not likely to be a limiting factor for the growth of phytoplankton. Silicate may, on the other hand, be reduced to a very small fraction of its original content, and in some stages of the phytoplankton production a shortage of silicate must limit the growth.

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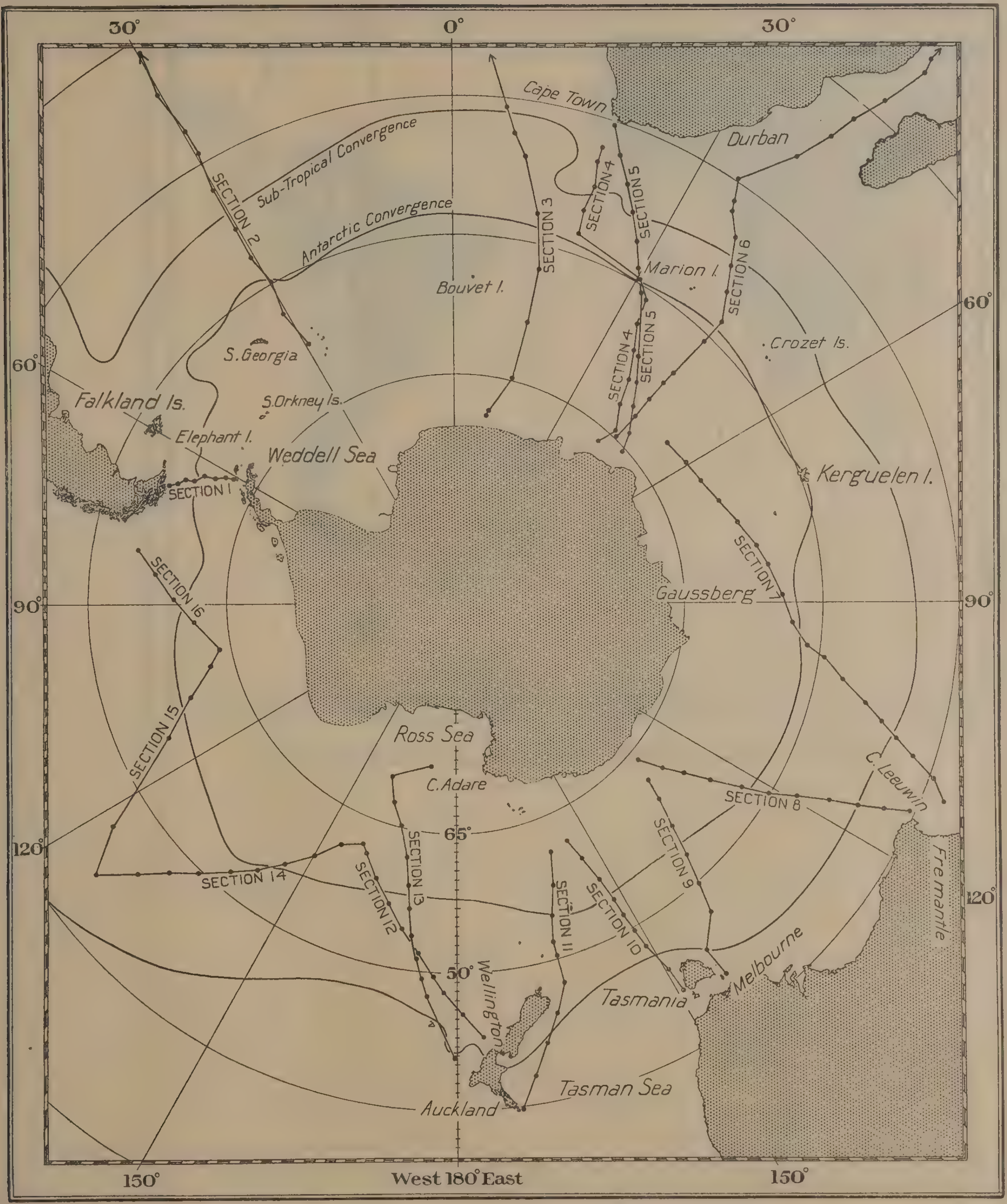
NOTE ON THE PLATES

Plates III–XXV show the distribution of phosphate and silicate in vertical sections along the lines marked sections 1–17 on the circumpolar chart in Plate I and in the complementary chart in Plate II. The amounts of phosphate and silicate are always expressed as milligrammes P_2O_5 or SiO_2 per cubic metre of sea water and are uncorrected for salt error.

Each of the sections has been drawn projected on to a meridian so that the horizontal distances do not represent actual distances along the sections but only differences of latitude. The latitude and depth scales have been maintained the same throughout so that the sections are comparable; the exaggeration of the vertical scale with respect to the horizontal scale is approximately 370 to 1.

The bottom profiles are only schematic.

The letters *AC* and *STC* above the sections mark the positions of the Antarctic and subtropical convergences.


30°
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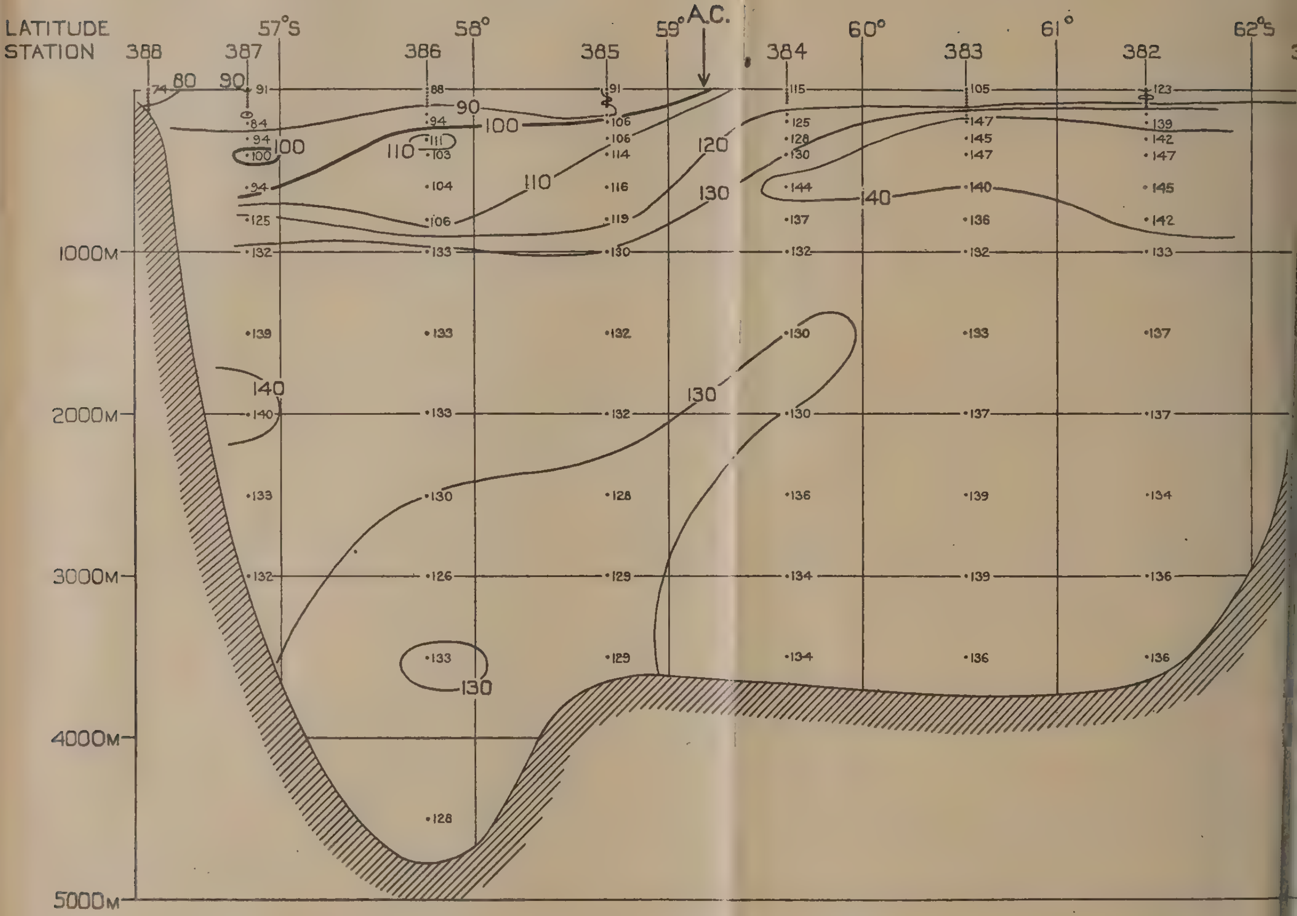
30°
Cape Town
Durban
Sub-Tropical Convergence
Antarctic Convergence
SECTION 2
SECTION 3
SECTION 4
SECTION 5
SECTION 6
Bouvet I.
Marion I.
Crozet Is.
60°
S. Georgia
60°
Falkland Is.
S. Orkney Is.
Elephant I.
Weddell Sea
SECTION 1
Kerguelen I.
SECTION 16
SECTION 7
90°
Gaussberg
90°
SECTION 15
Ross Sea
C. Leeuwin
C. Adare
SECTION 8
120°
65°
SECTION 9
SECTION 14
SECTION 12
SECTION 13
SECTION 11
SECTION 10
Fremantle
120°
50°
Wellington
Melbourne
Tasmania
Tasman Sea
Auckland
150°
West 180° East
150°

Chart of the Southern Ocean showing the positions of sections 1–17.



The distribution of phosphate along section 1 in the Drake Passage. Ap

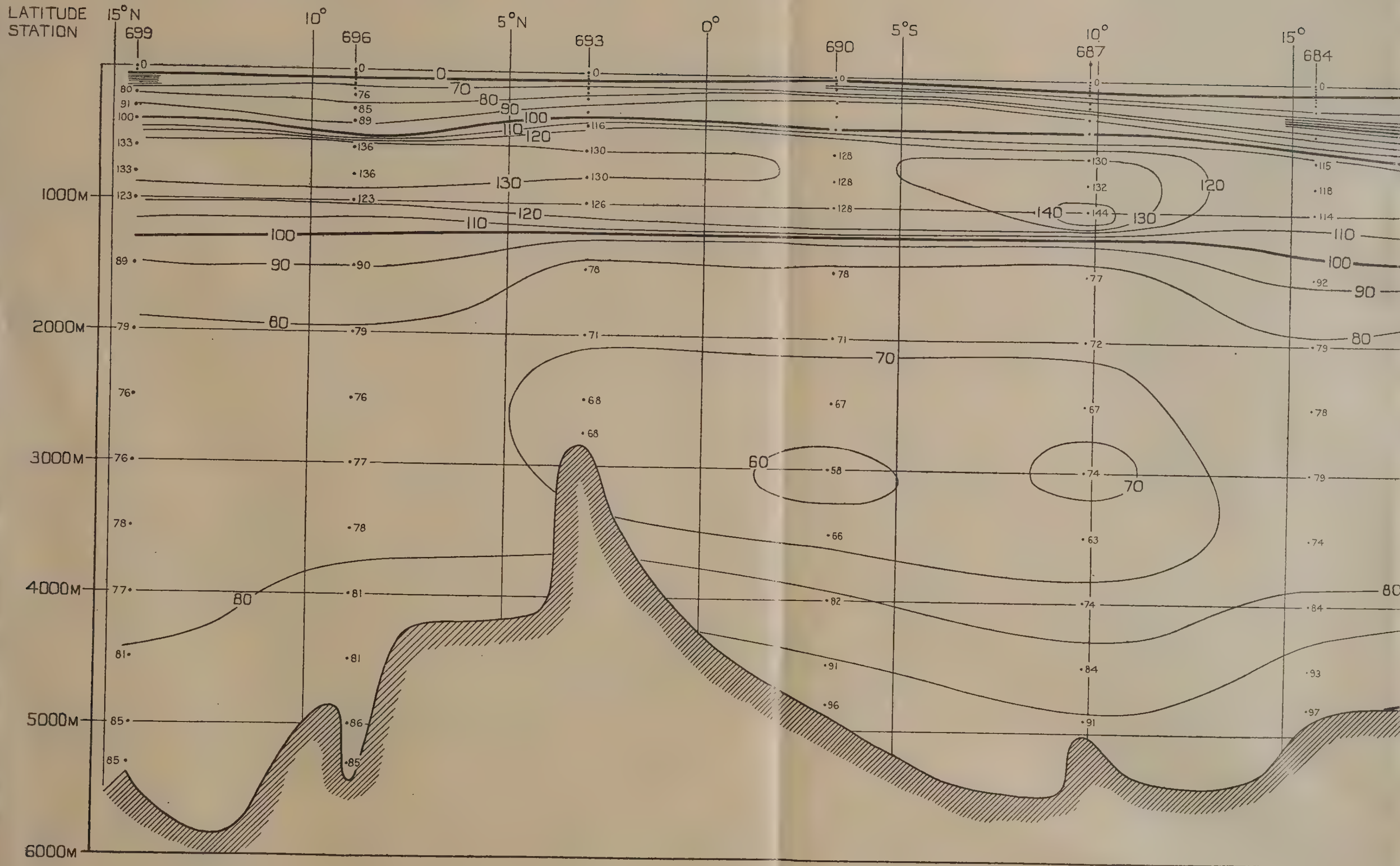

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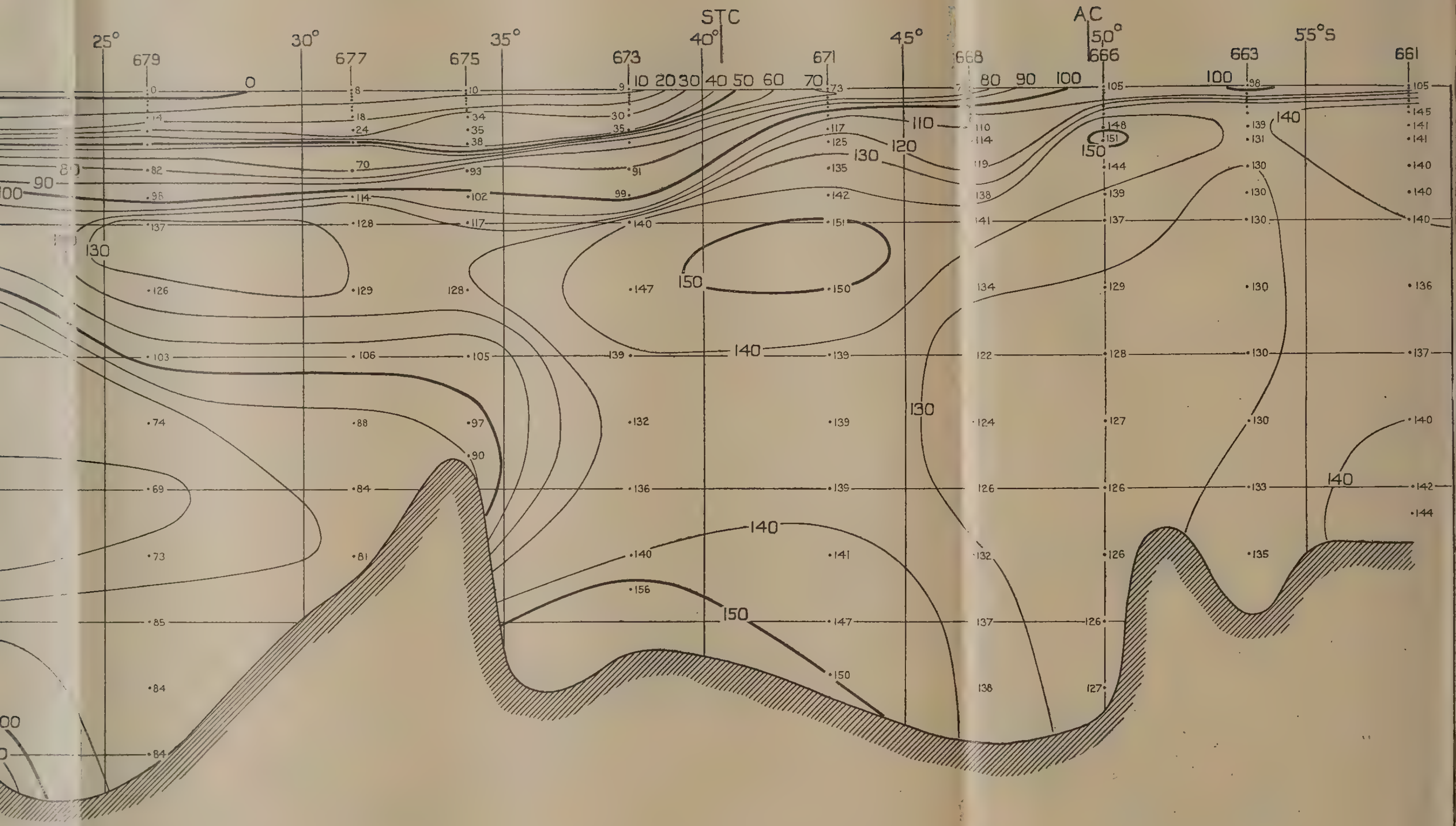
PLATE IV



The distribution of phosphate along section 2, a longitudinal section in 30° W fro
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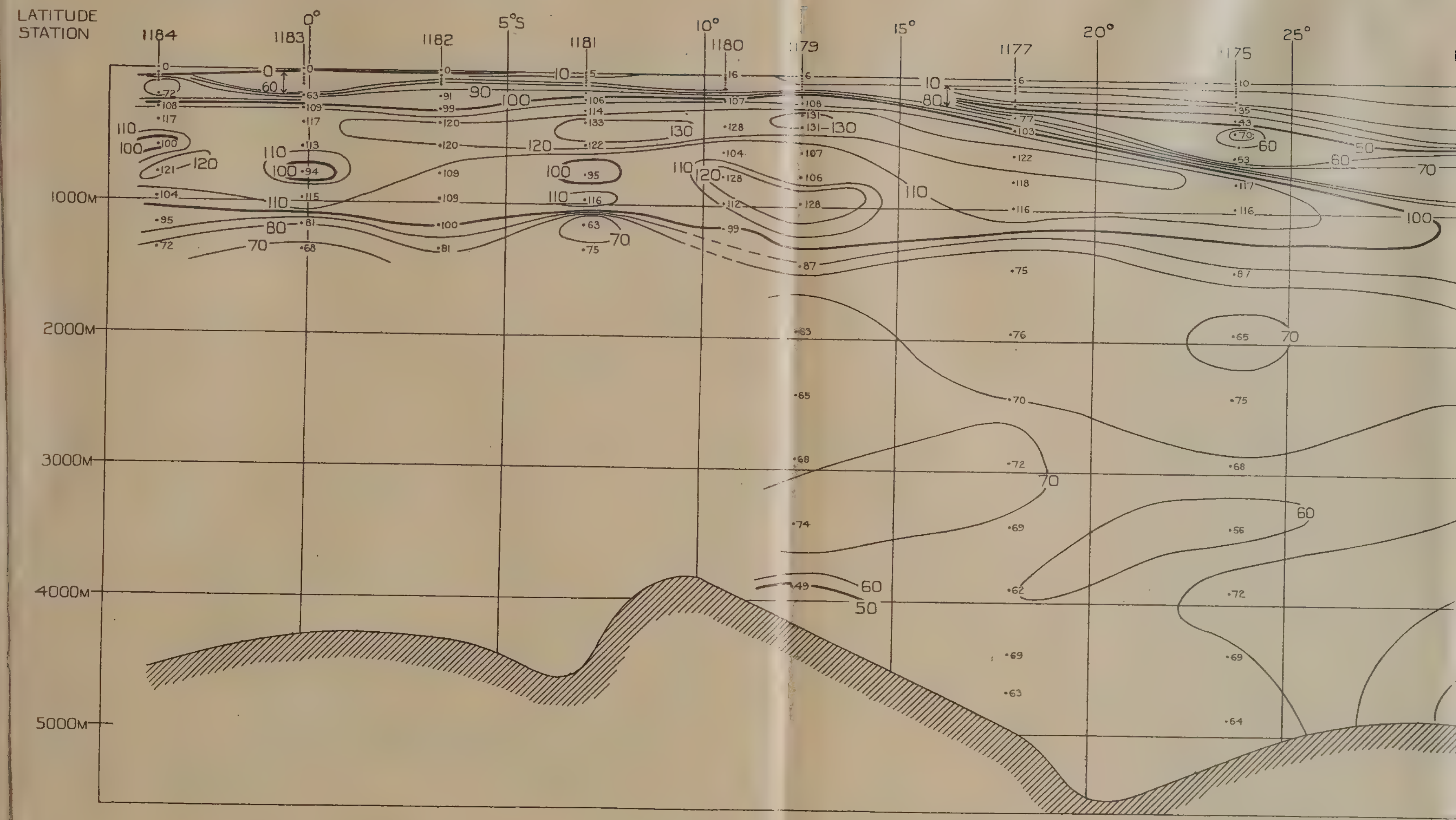
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1175
25°
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5000M
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100
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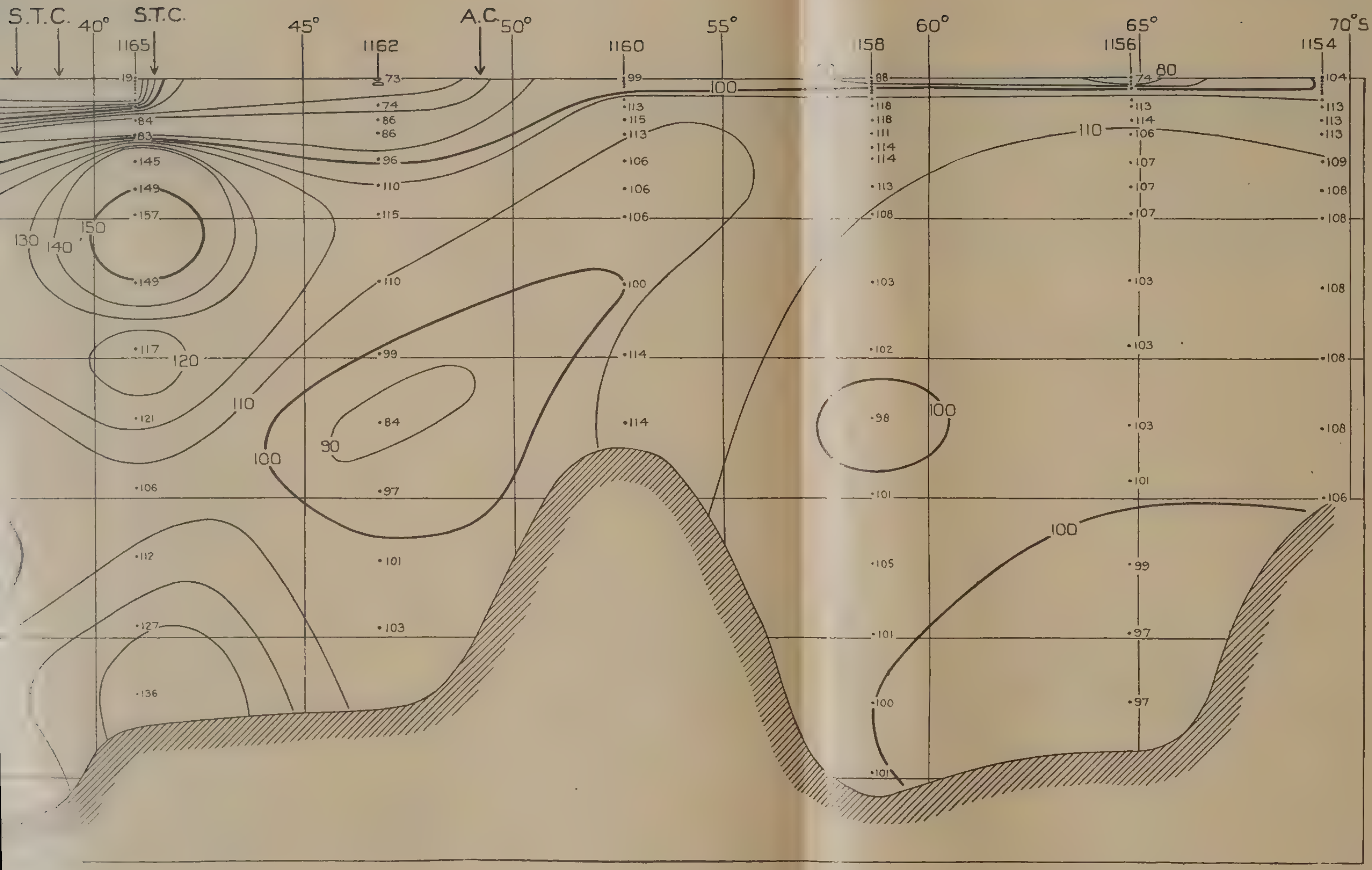
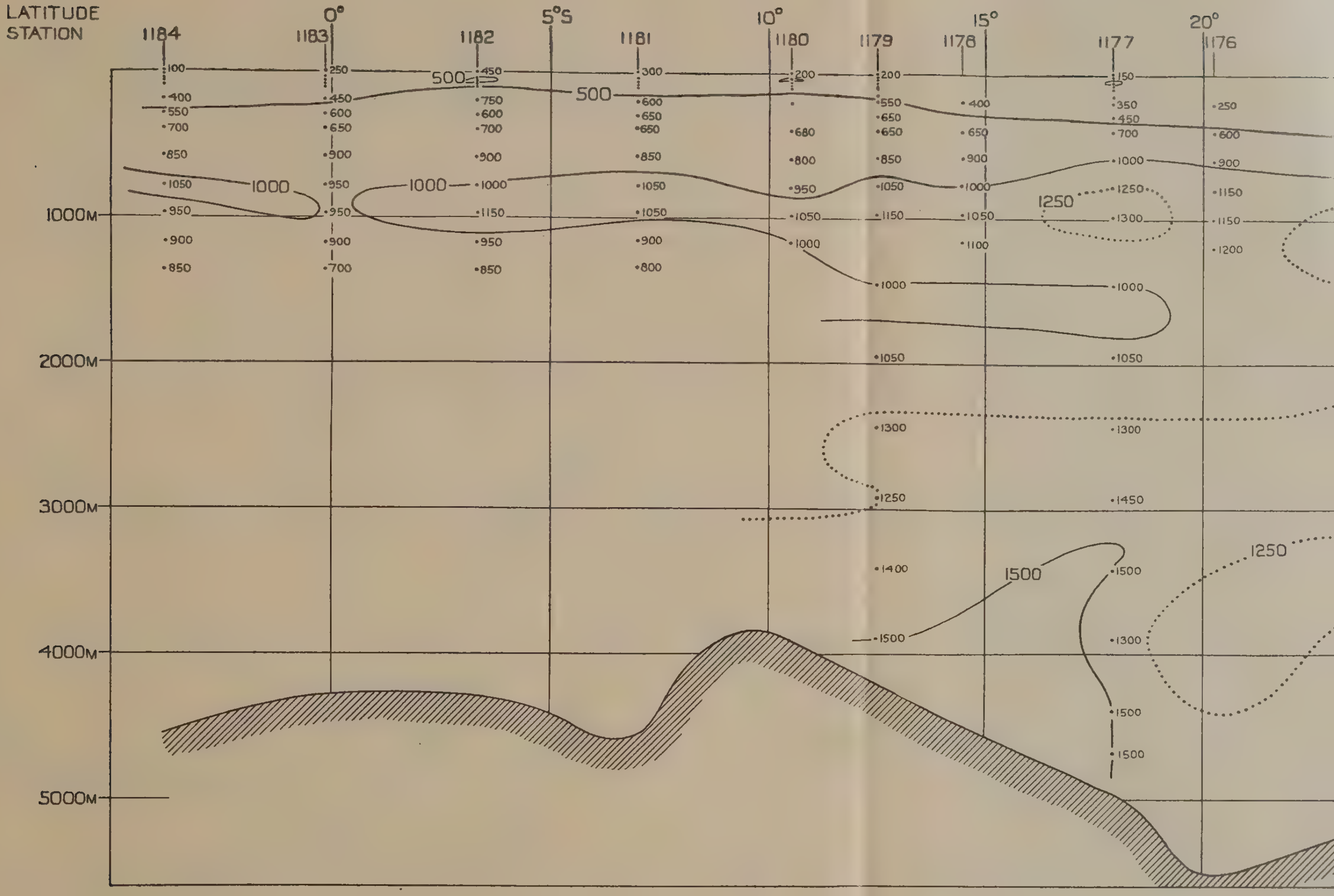
70
50
60

PLATE V



The distribution of phosphate along section 3, a longitudinal section in 14° E–13° W from the ice-edge in 69° 20′ S to 3° 46′ N. March–April 1933.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1000
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950
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650
650
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900
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200
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800
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200
550
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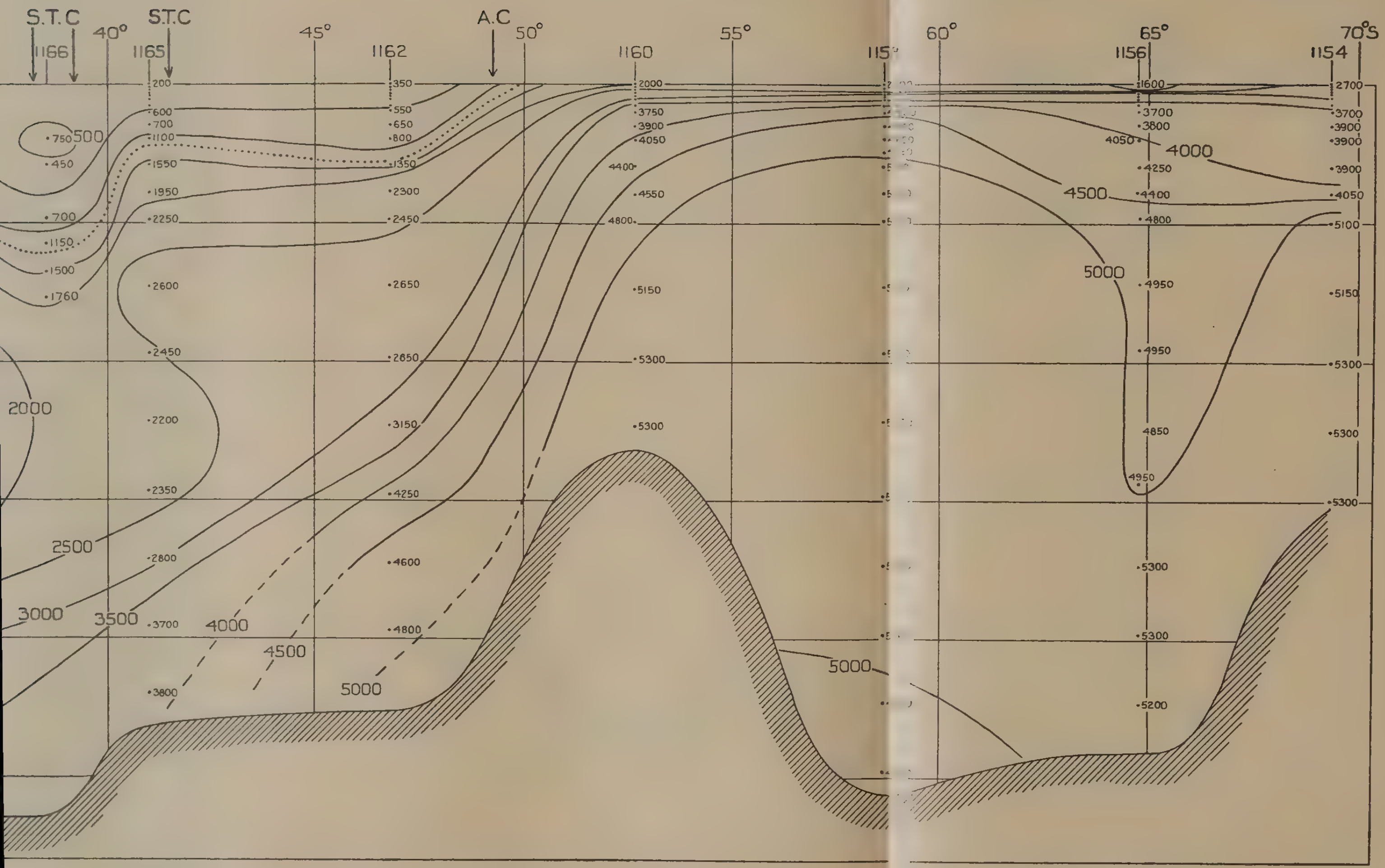
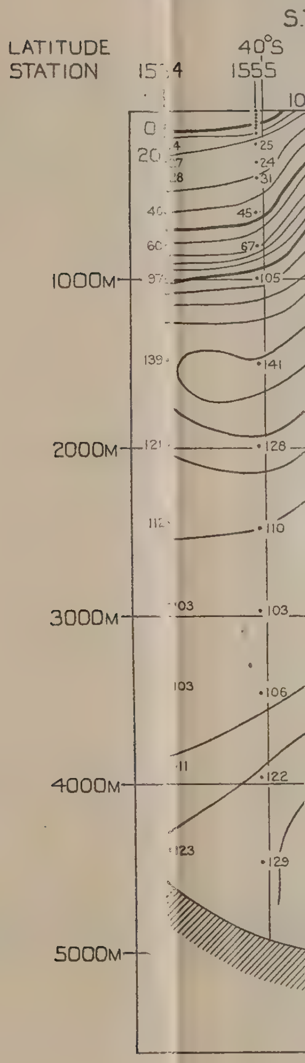


The distribution of silicate along section 3, a longitudinal section in 14° E–13° W from the ice-edge in 69° 20′ S to 3° 46′ N. March–April 1933.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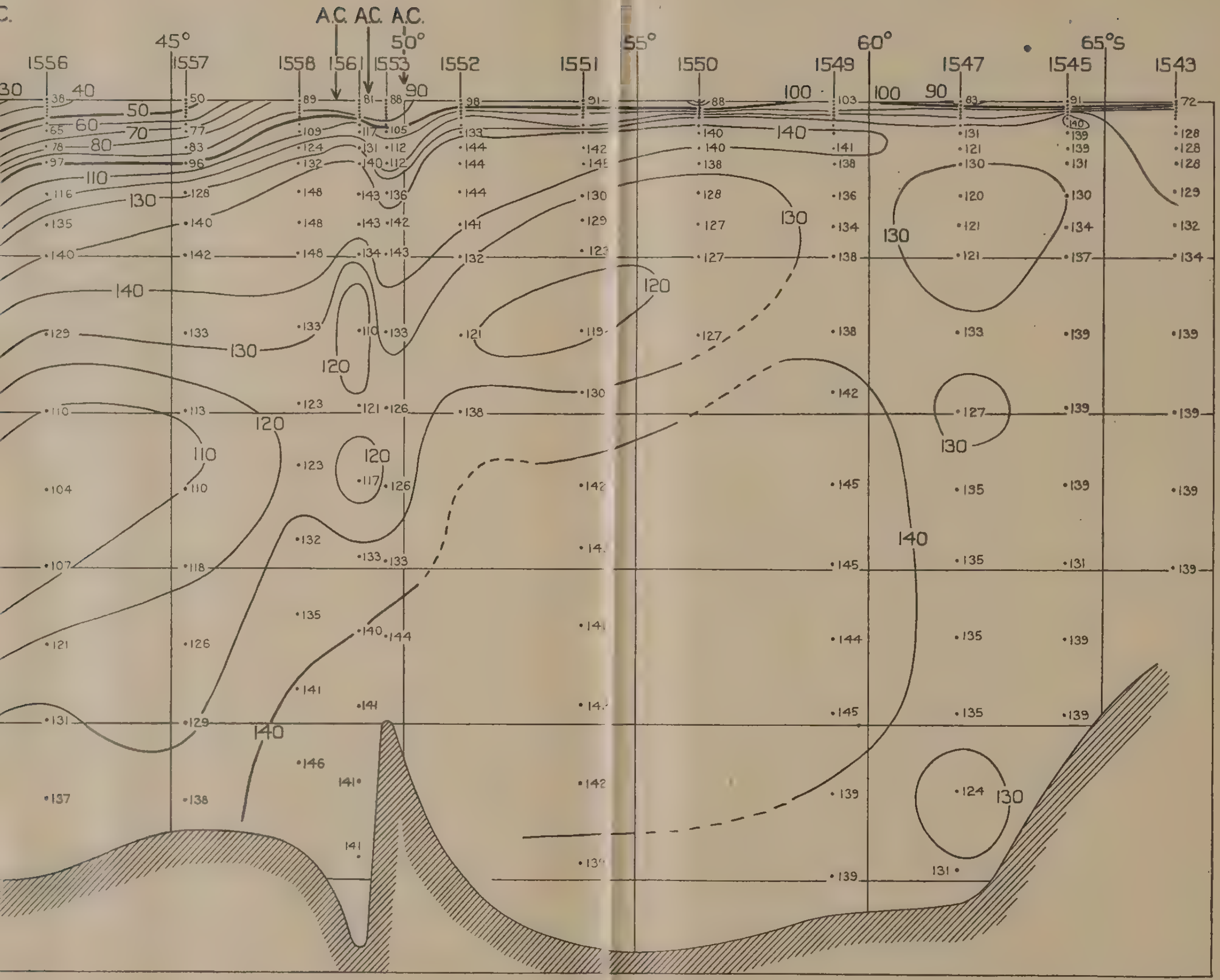
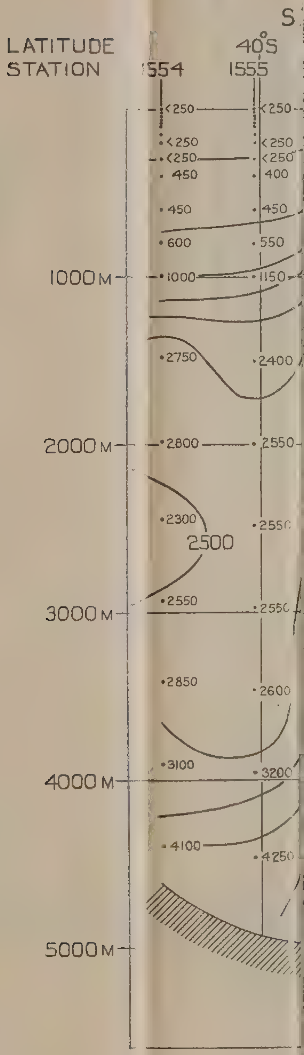


The distribution of phosphate along section 4, from Cape Town to the ice-edge in 66½° S, 42½° E, north of Enderby Land. February–March 1935.

DISCOVERY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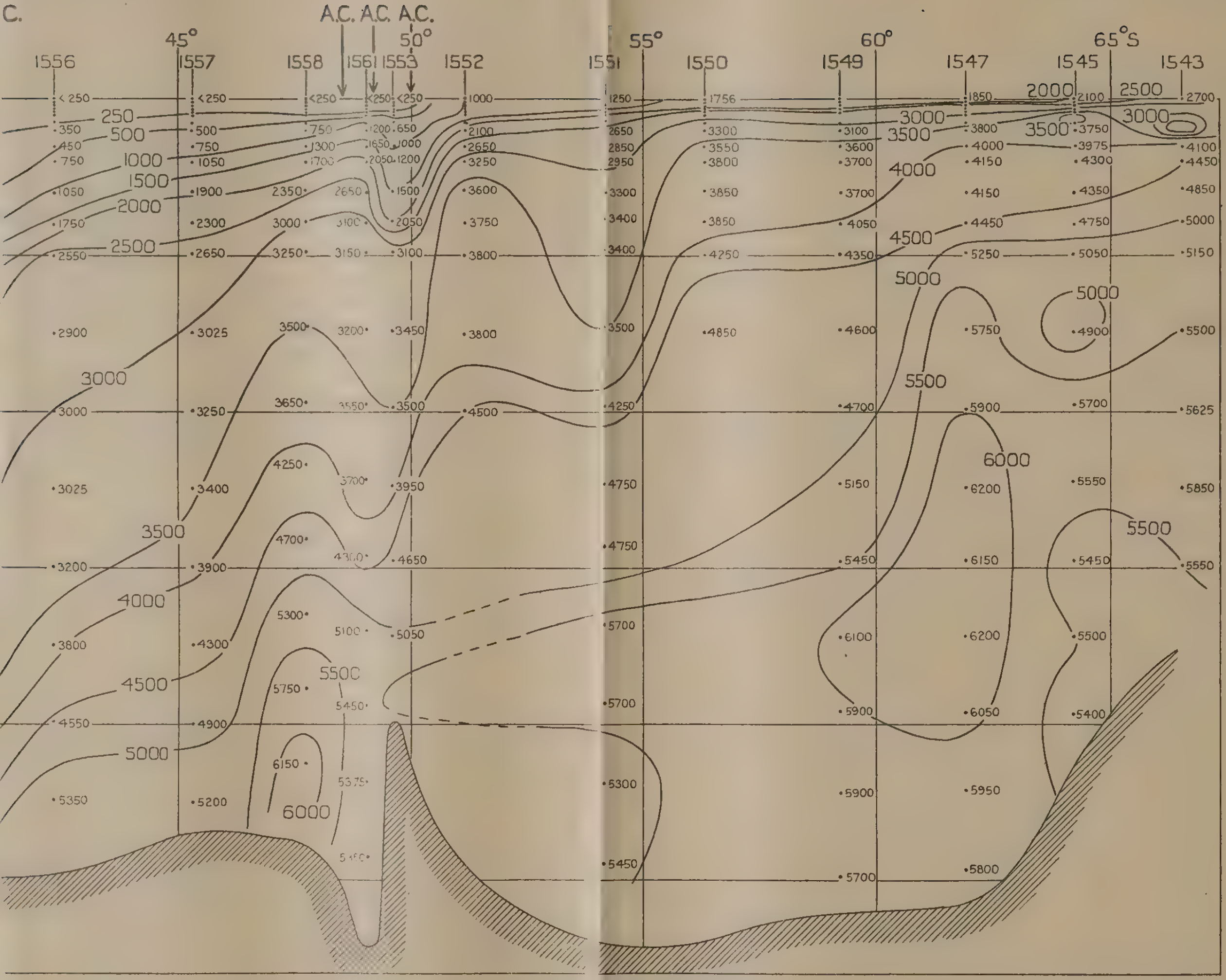
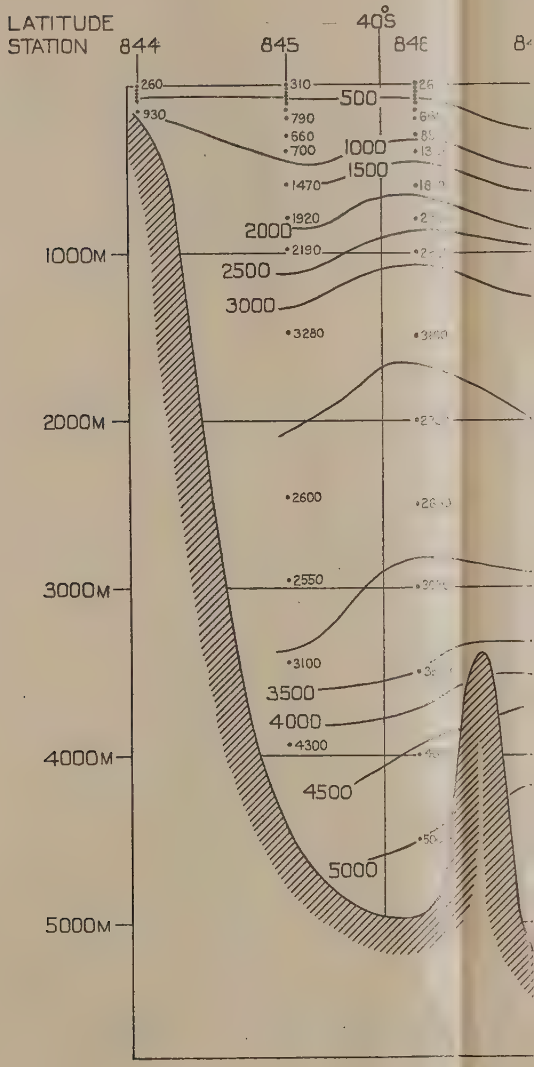
5000 M



The distribution of silicate along section 4, from Cape Town to the ice-edge, in 66½° S, 42½° E, north of Enderby Land. February–March 1935.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500
930
790
660
700
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1500
1470
1920
2000
2190
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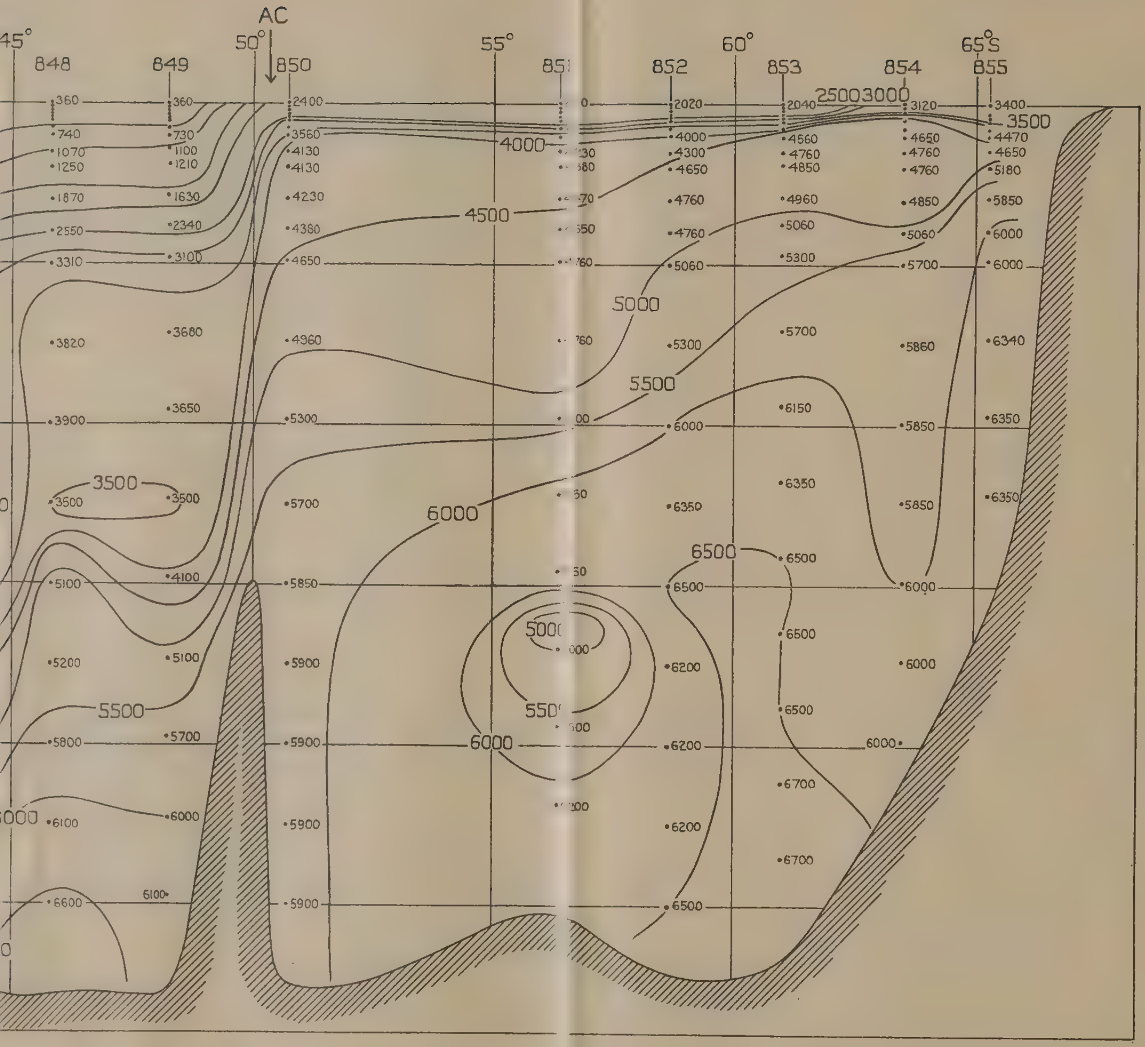
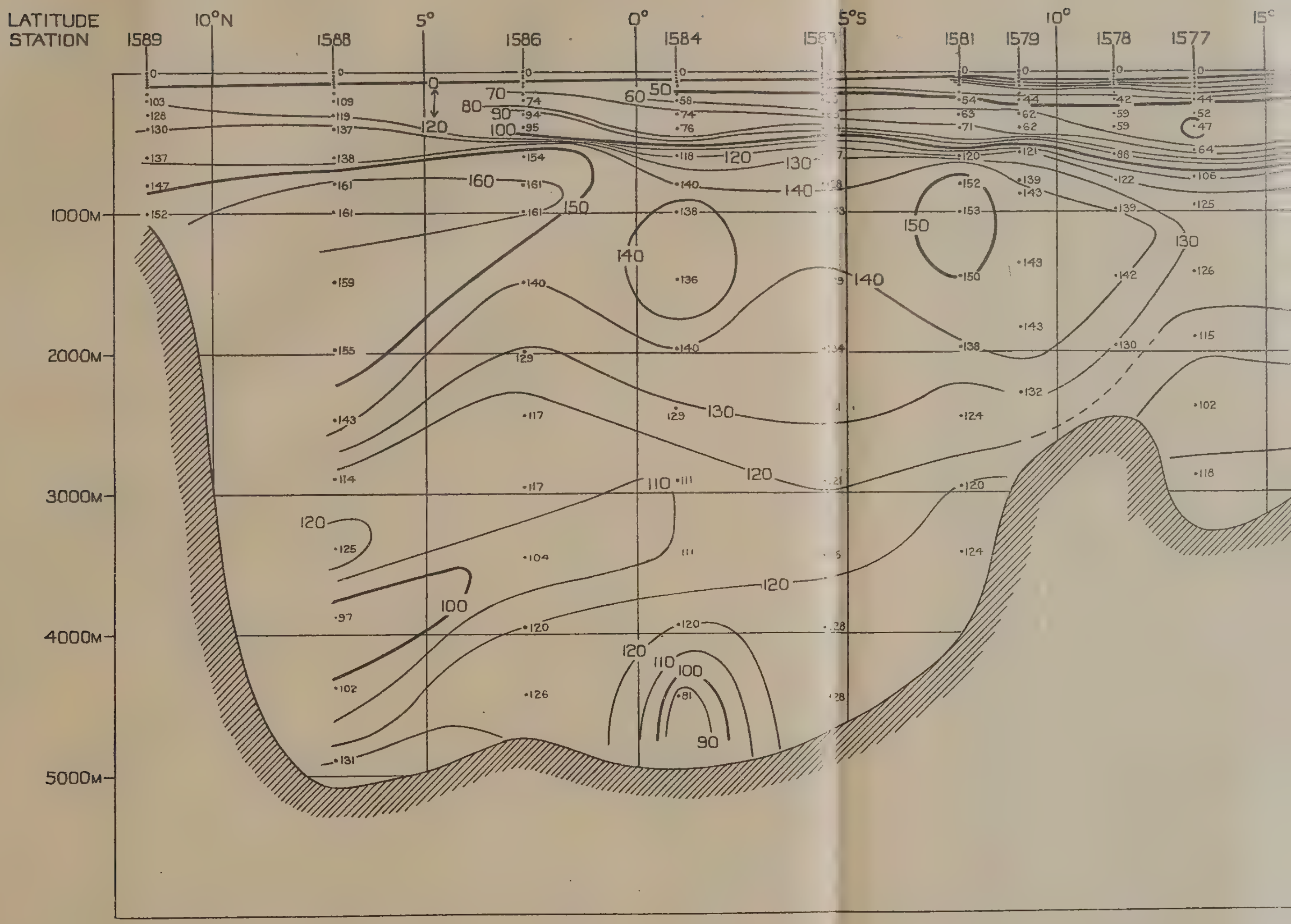


The distribution of silicate along section 5, from Cape Town to the ice-edge in 65° 15′ S, 48° 44′ E north of Enderby Land. April 1932.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STATION
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5°
0°
5°S
10°
15°
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1588
1586
1584
1581
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1577
1000M
2000M
3000M
4000M
5000M
0
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70
80
90
100
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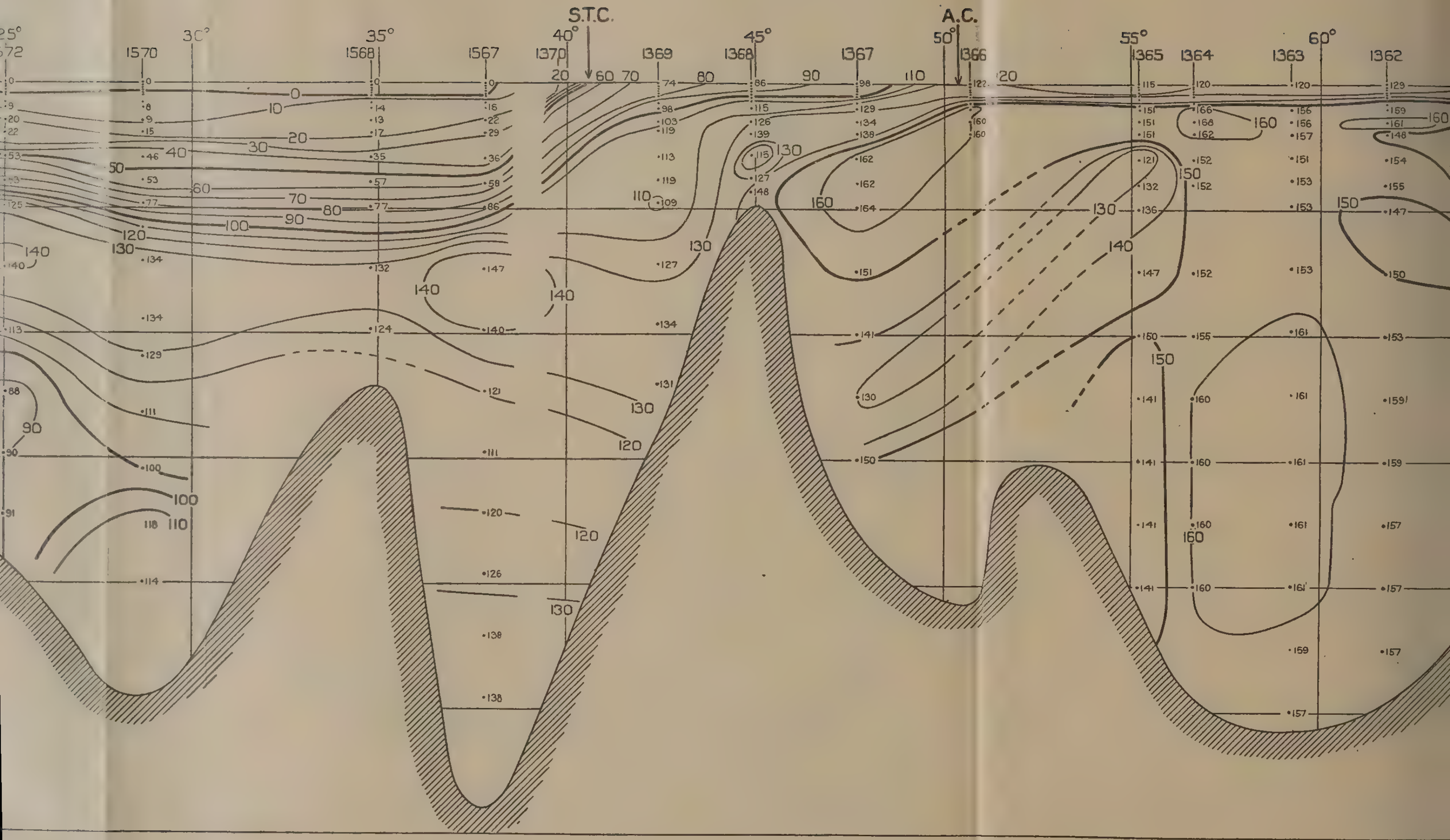
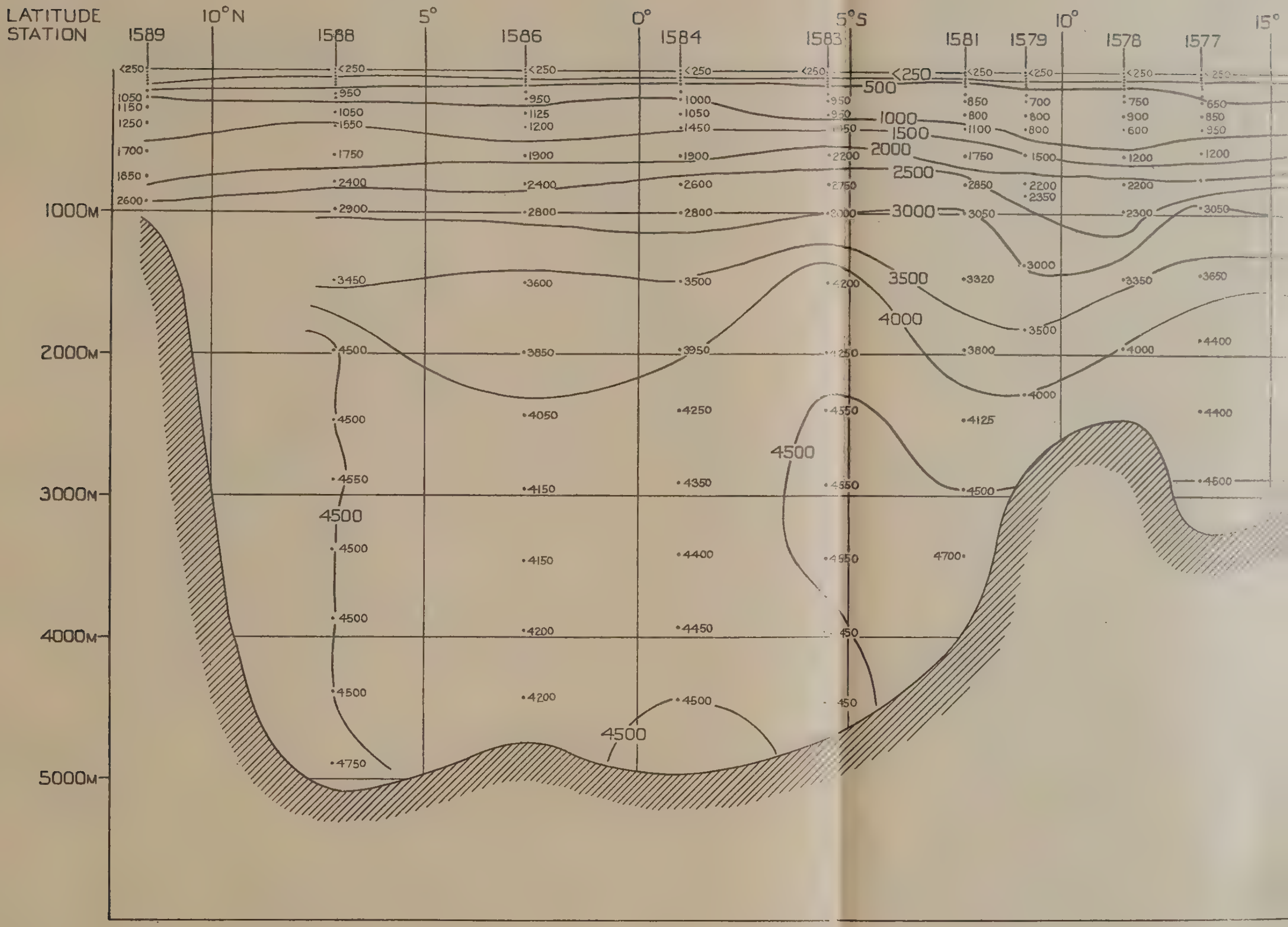
90



The distribution of phosphate along section 6, a longitudinal section in 34–5
the ice-edge in 64° 38′ S to 11° 32′ N. May 1934 and April–May 1935.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0°
5°S
10°
15°
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1588
1586
1584
1583
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1578
1577
1000M
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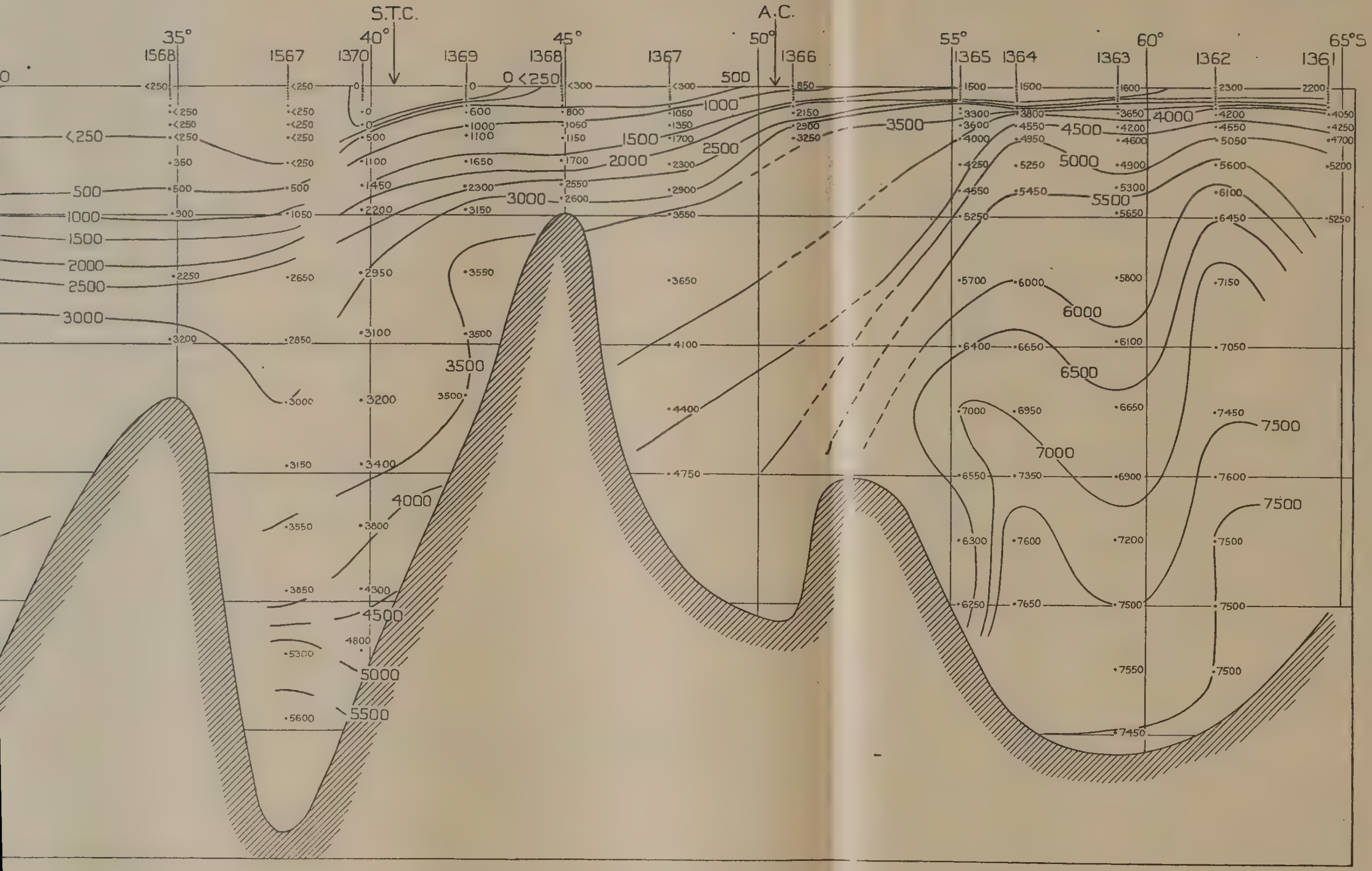
4500
4500
4500
4700



The distribution of silicate along section 6, a longitudinal section in 34–52° E from the ice-edge in 64° 38′ S to 11° 32′ N. May 1934 and April–May 1935.

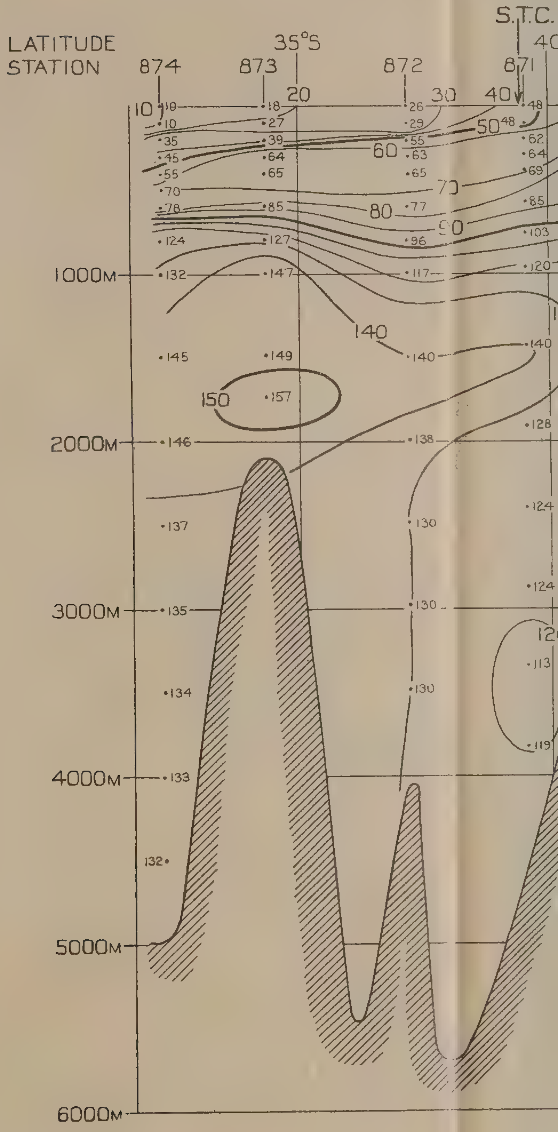
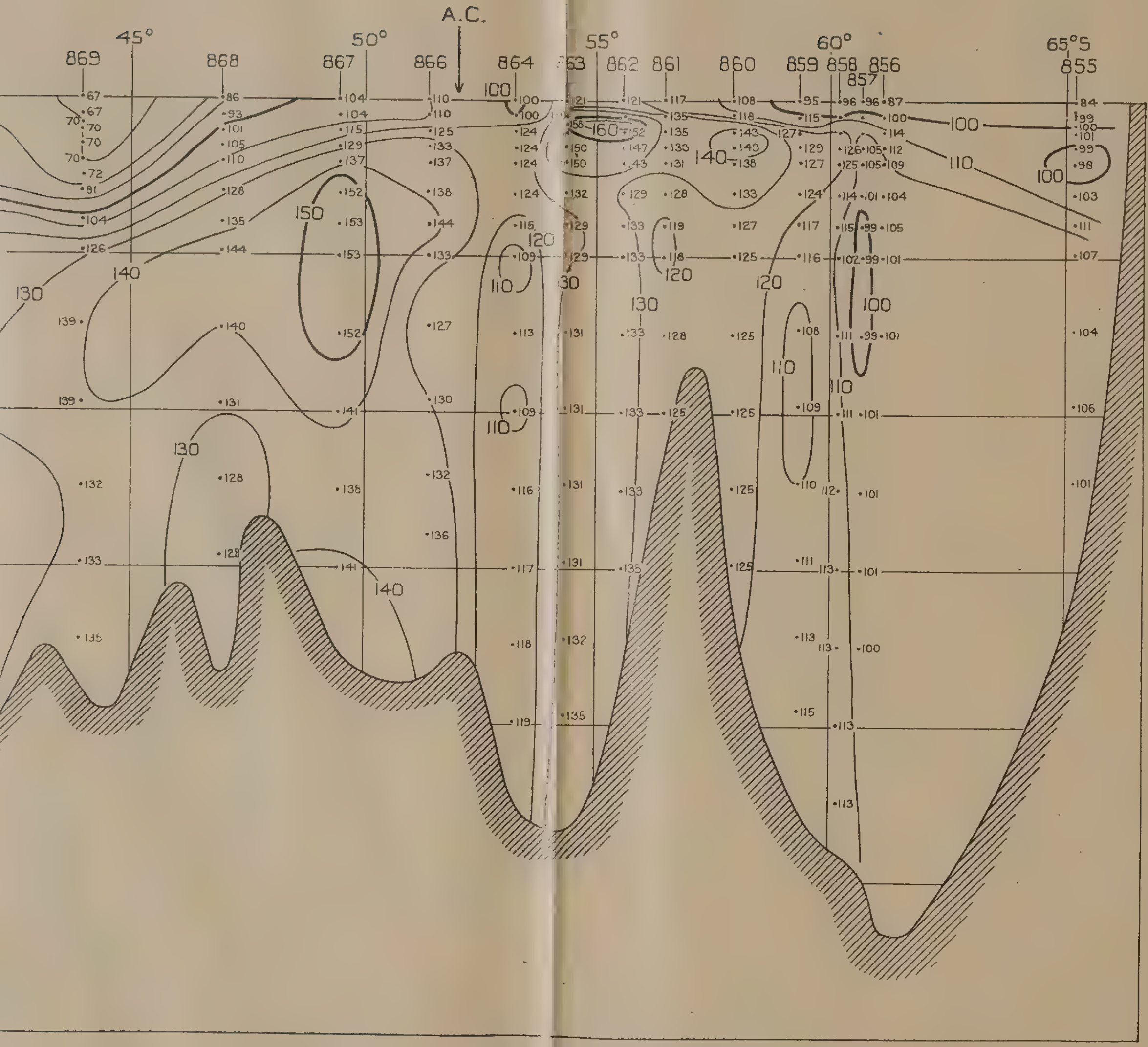
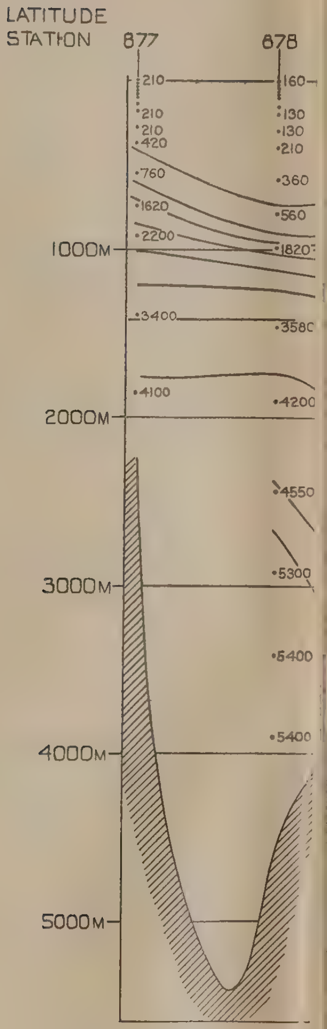

S.T.C.
LATITUDE
STATION
35°S
40
874
873
872
871
10
20
30
40
50
60
70
80
90
140
150
1000M
2000M
3000M
4000M
5000M
6000M
·18
·10
·35
·45
·55
·70
·78
·124
·132
·145
·146
·137
·135
·134
·133
132·
·18
·27
·39
·64
·65
·85
·127
·147
·149
·157
·26
·29
·55
·63
·65
·77
·96
·117
·140
·138
·130
·130
·130
·48
·62
·64
·69
·85
·103
·120
·140
·128
·124
·124
·113
·119

PLATE XII



The distribution of phosphate along section 7, from the ice-edge in 65° 15′ S, 48° 44′ E north of Enderby Land to Fremantle, Australia. April–May 1932.


LATITUDE
STATION
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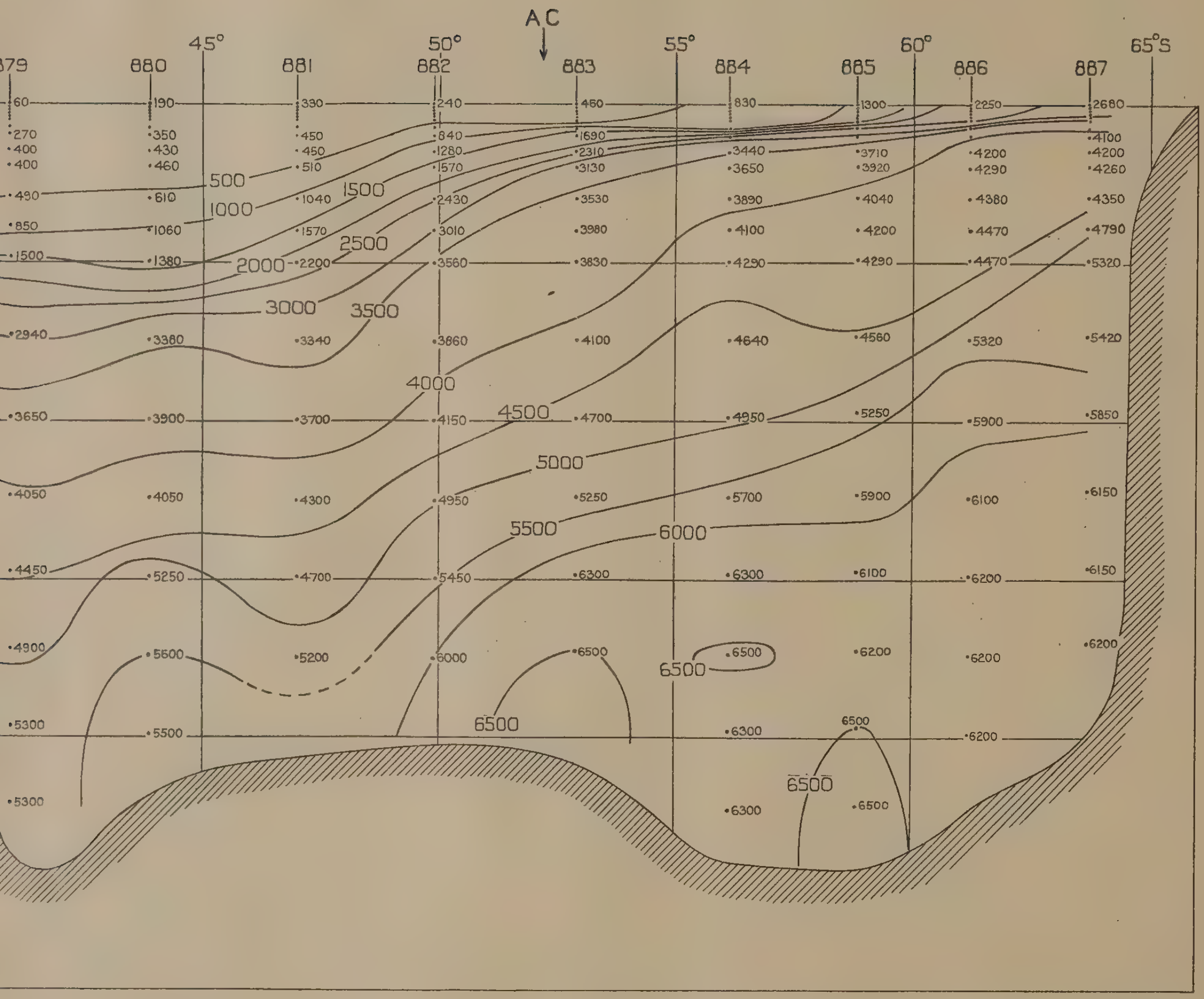
878
210
160
210
210
420
130
130
210
760
360
1620
560
2200
1820
1000M
3400
3580
4100
4200
2000M
4550
5300
3000M
5400
5400
4000M
5000M



The distribution of silicate along section 8 from Cape Leeuwin, Western Australia, to the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia. May 1932.

LATITU
STATIO

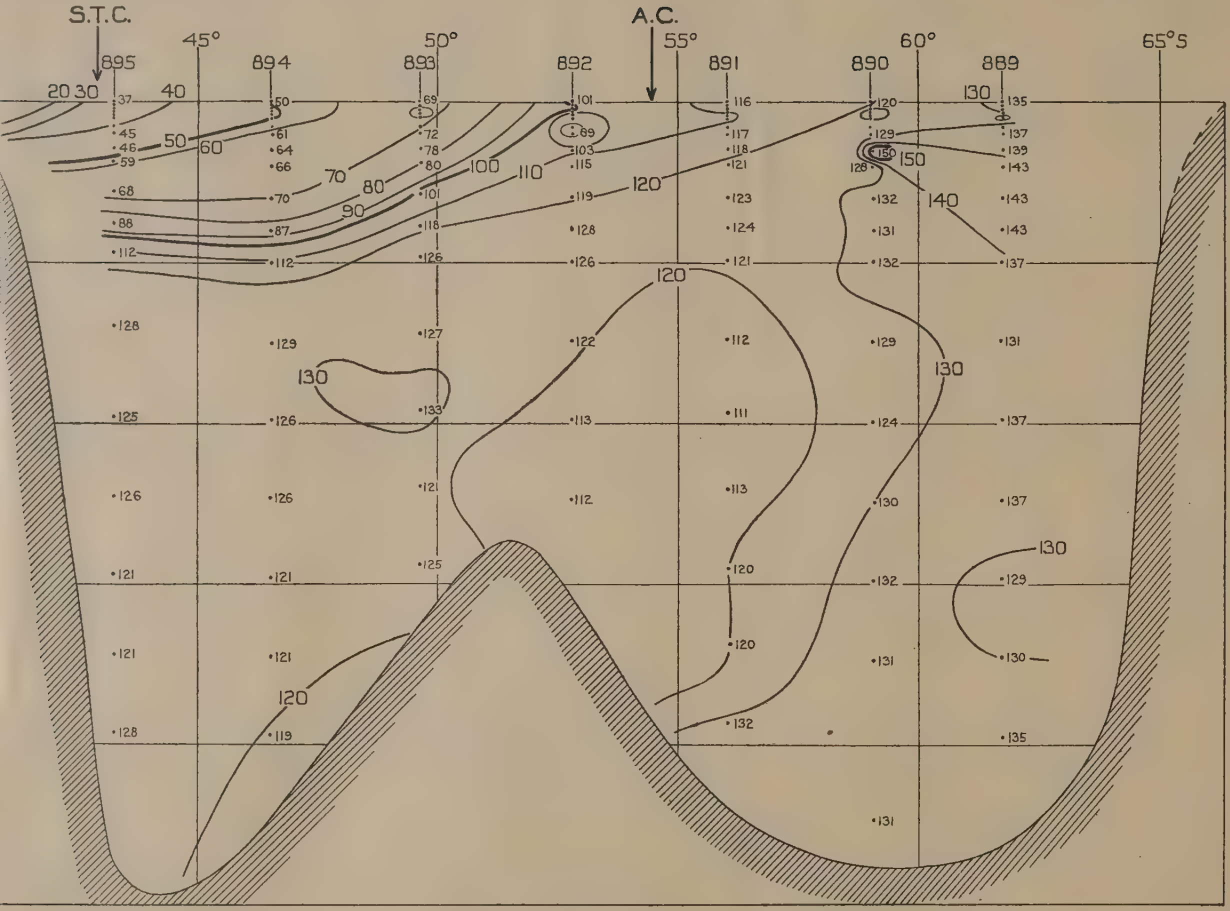
100

200

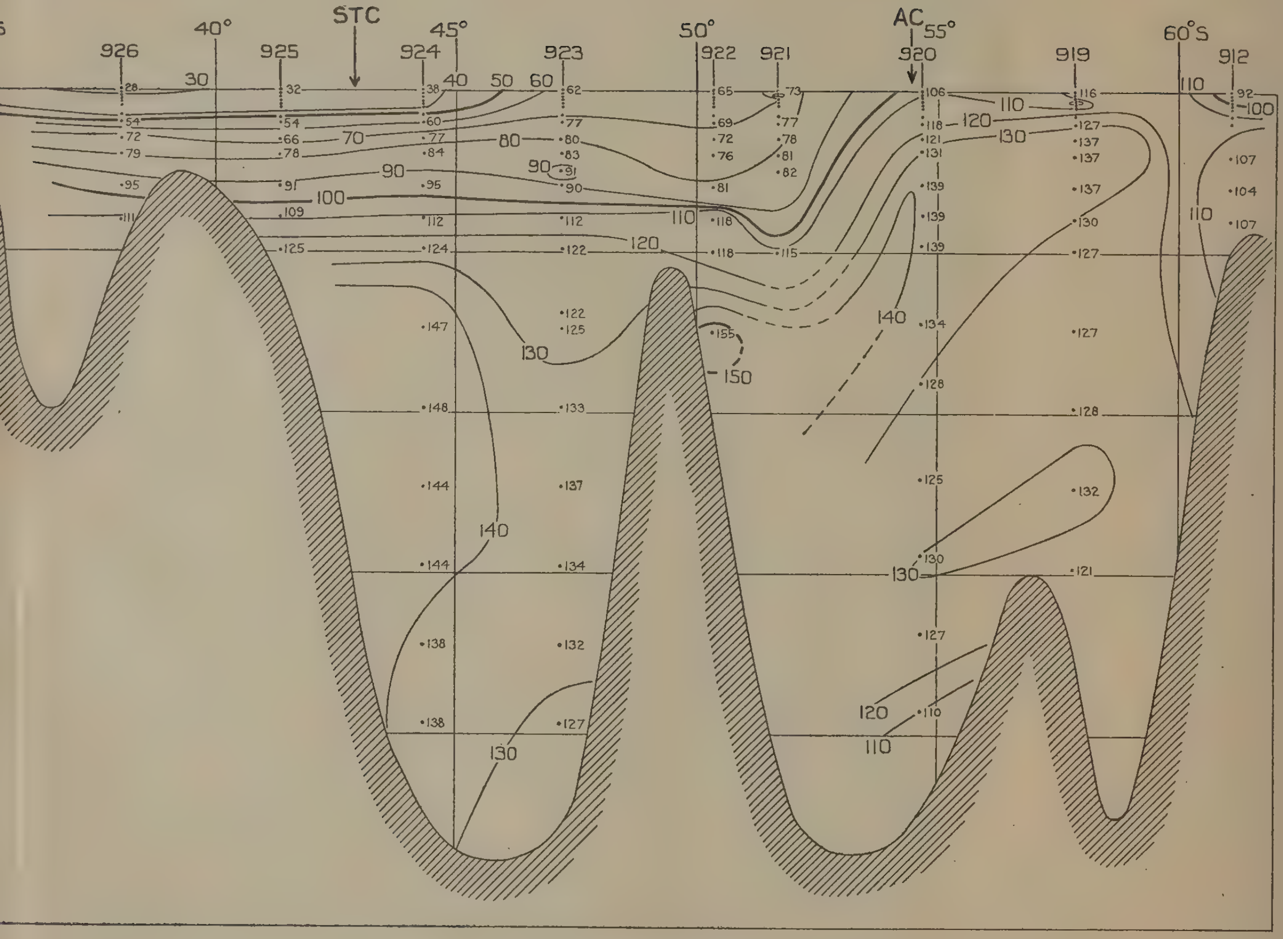
300

400

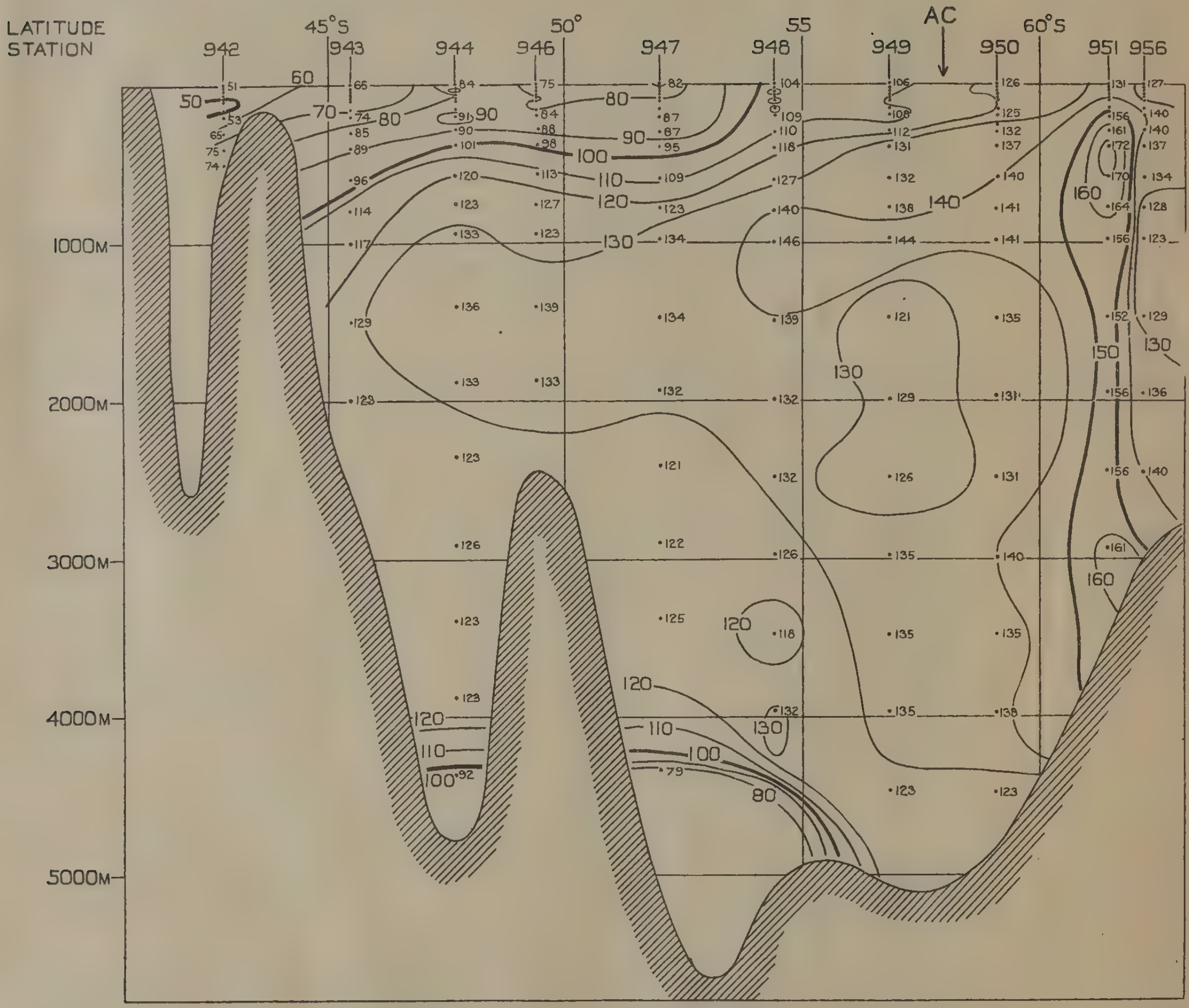
500



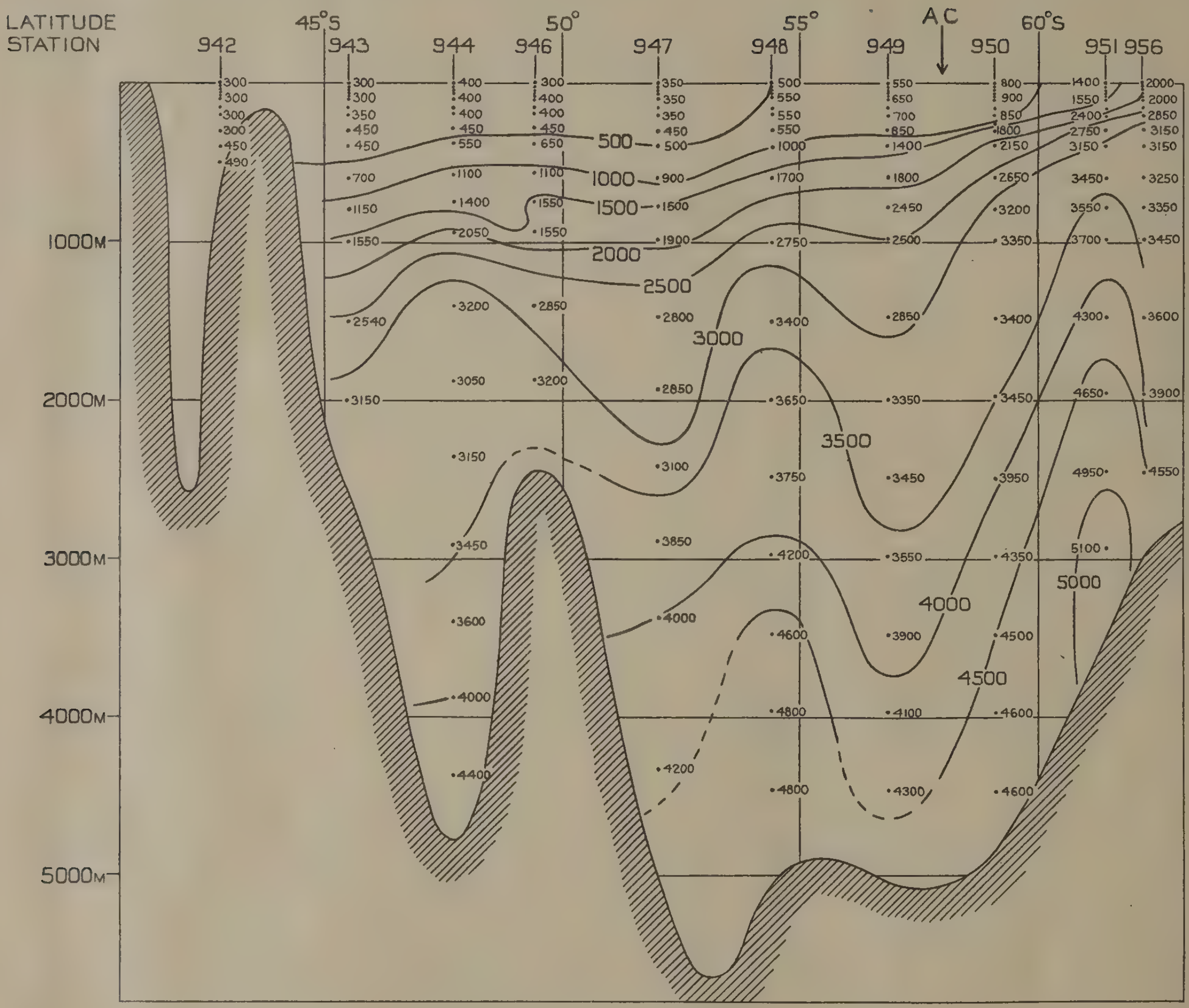
The distribution of phosphate along section 9 from the ice-edge in 63° 41′ S, 130° 07′ E, south of Australia, to Melbourne, Victoria. May–June 1932.



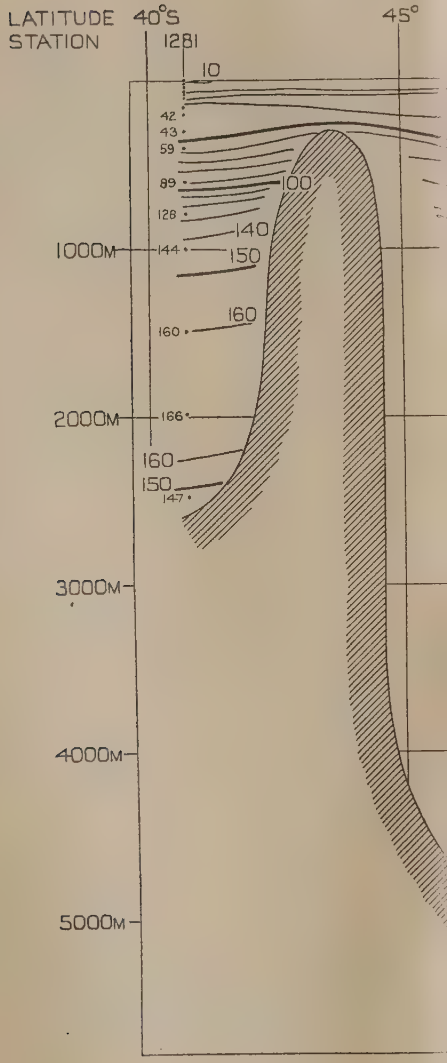
The distribution of phosphate along section 11 from the ice-edge in 61° 05′ S, 158° 26′ E, south of the Tasman Sea, to North Cape, New Zealand. June–July 1932.



The distribution of phosphate along section 12, from Wellington, New Zealand, to the ice-edge in 62° 13′ S, 158° 11′ W, north of the Ross Sea. September 1932.



The distribution of silicate along section 12, from Wellington, New Zealand, to the ice-edge in 62° 13′ S, 158° 11′ W, north of the Ross Sea. September 1932.


LATITUDE
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45°
STATION
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10
42
43
59
89
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128
140
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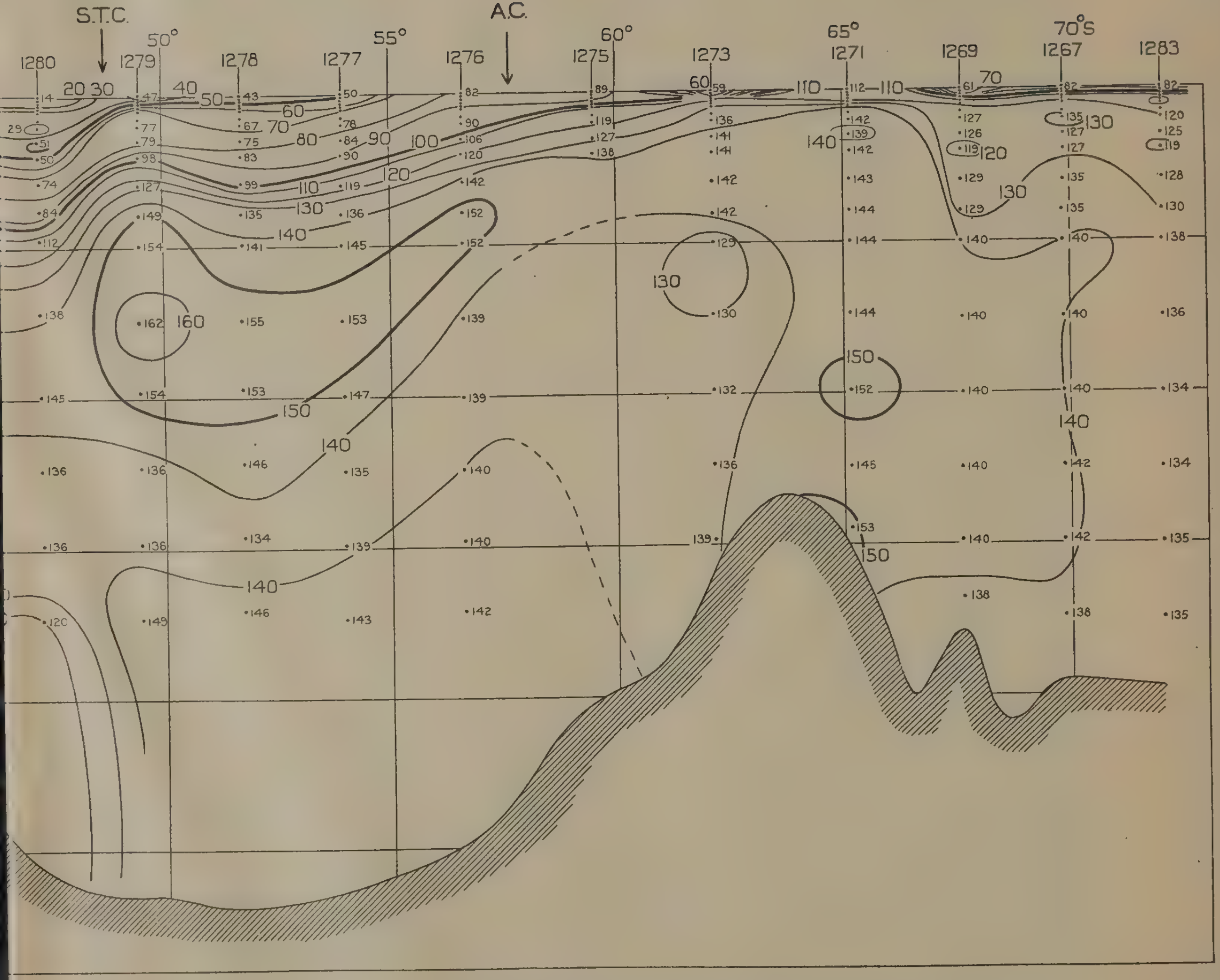
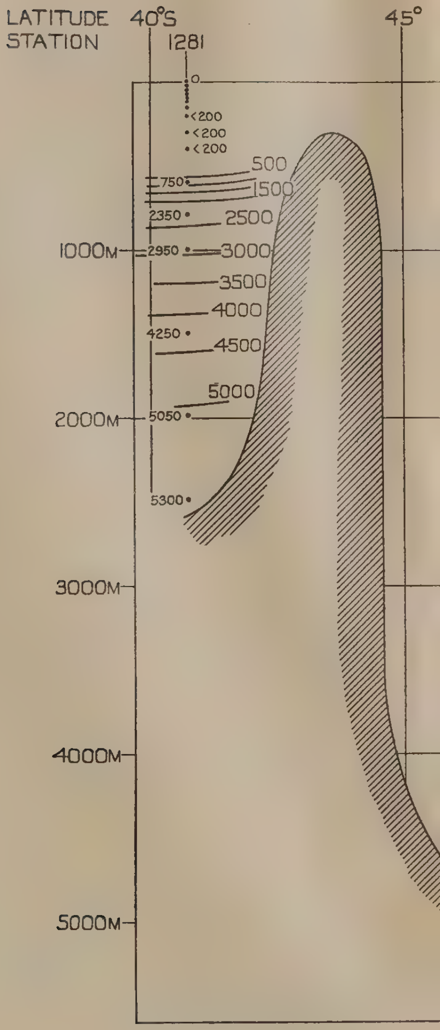
150
147
3000M
4000M
5000M



The distribution of phosphate along section 13, from the ice-edge in 72° 01′ S, 171° 26′ W, north of the Ross Sea, to Auckland, New Zealand. January 1934.


LATITUDE
STATION
40°S
45°
1281
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<200
<200
500
750
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2500
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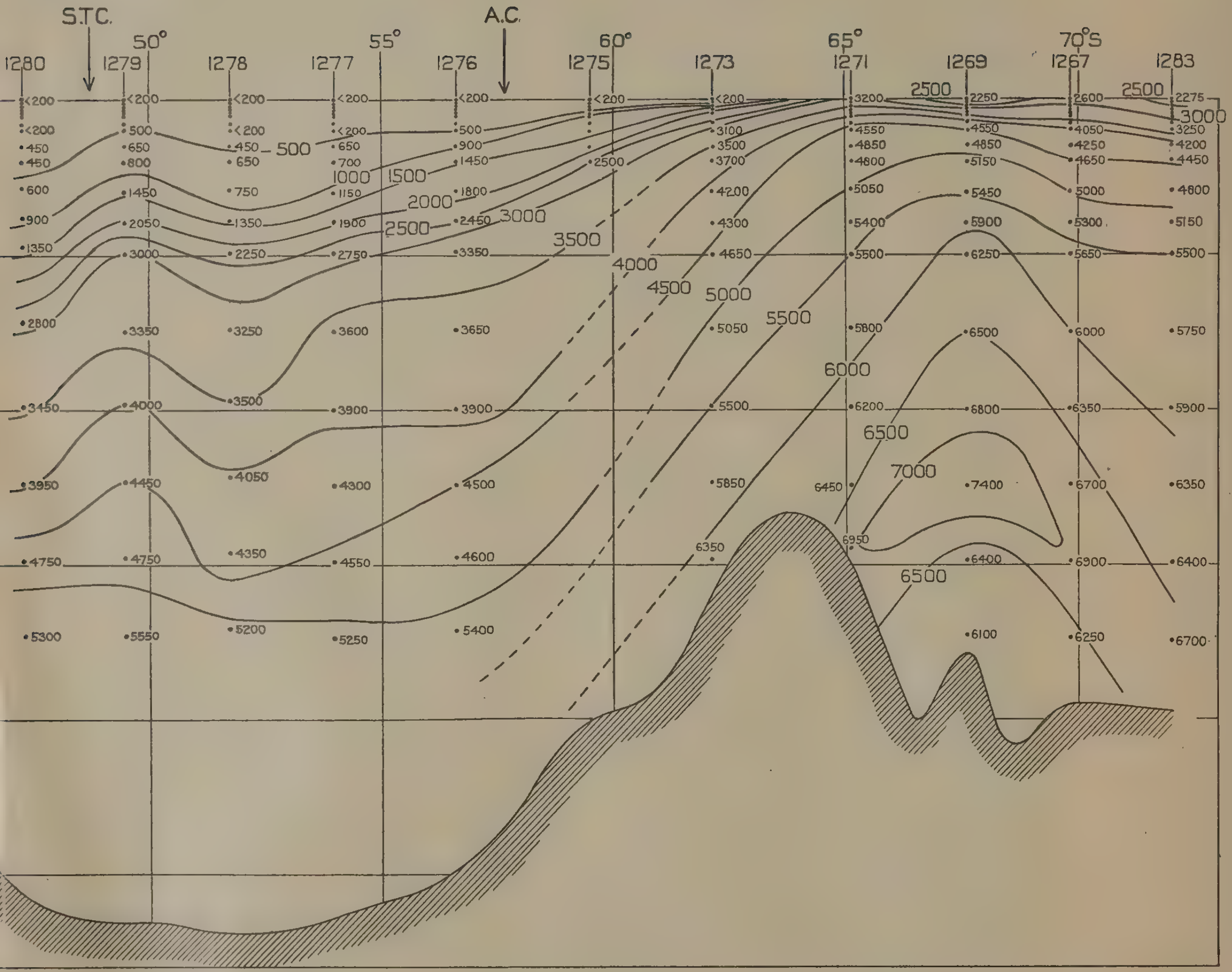
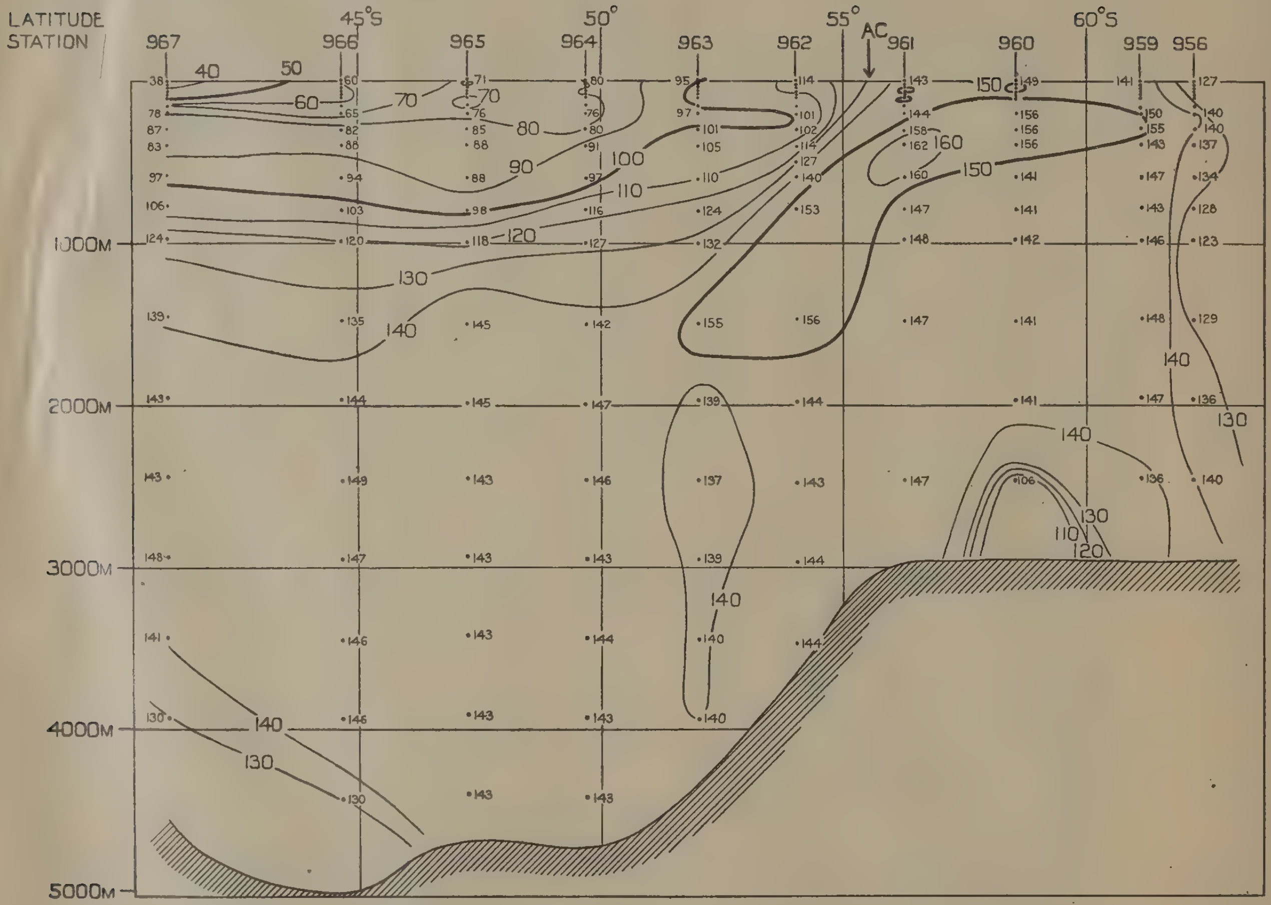
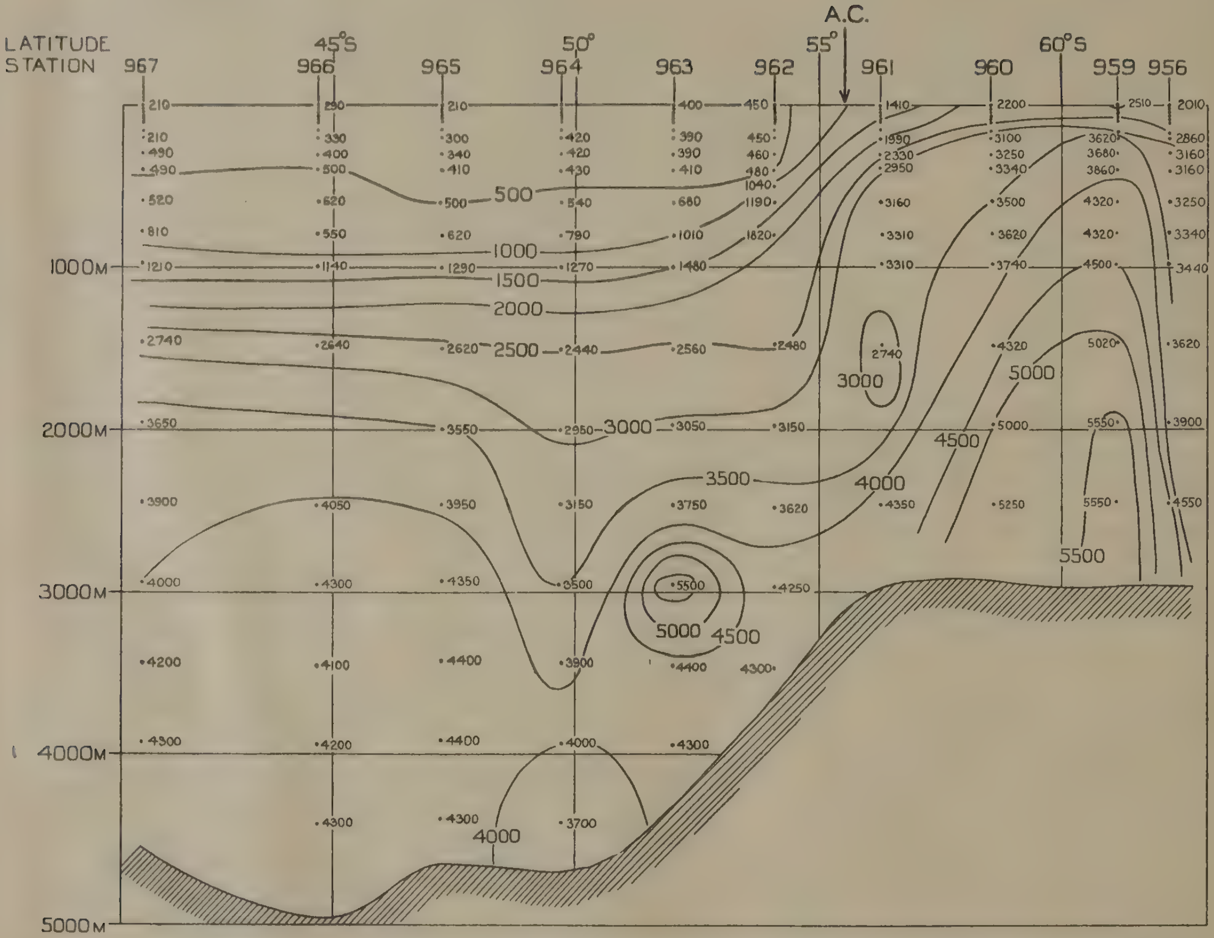
2000M
3000M
4000M
5000M



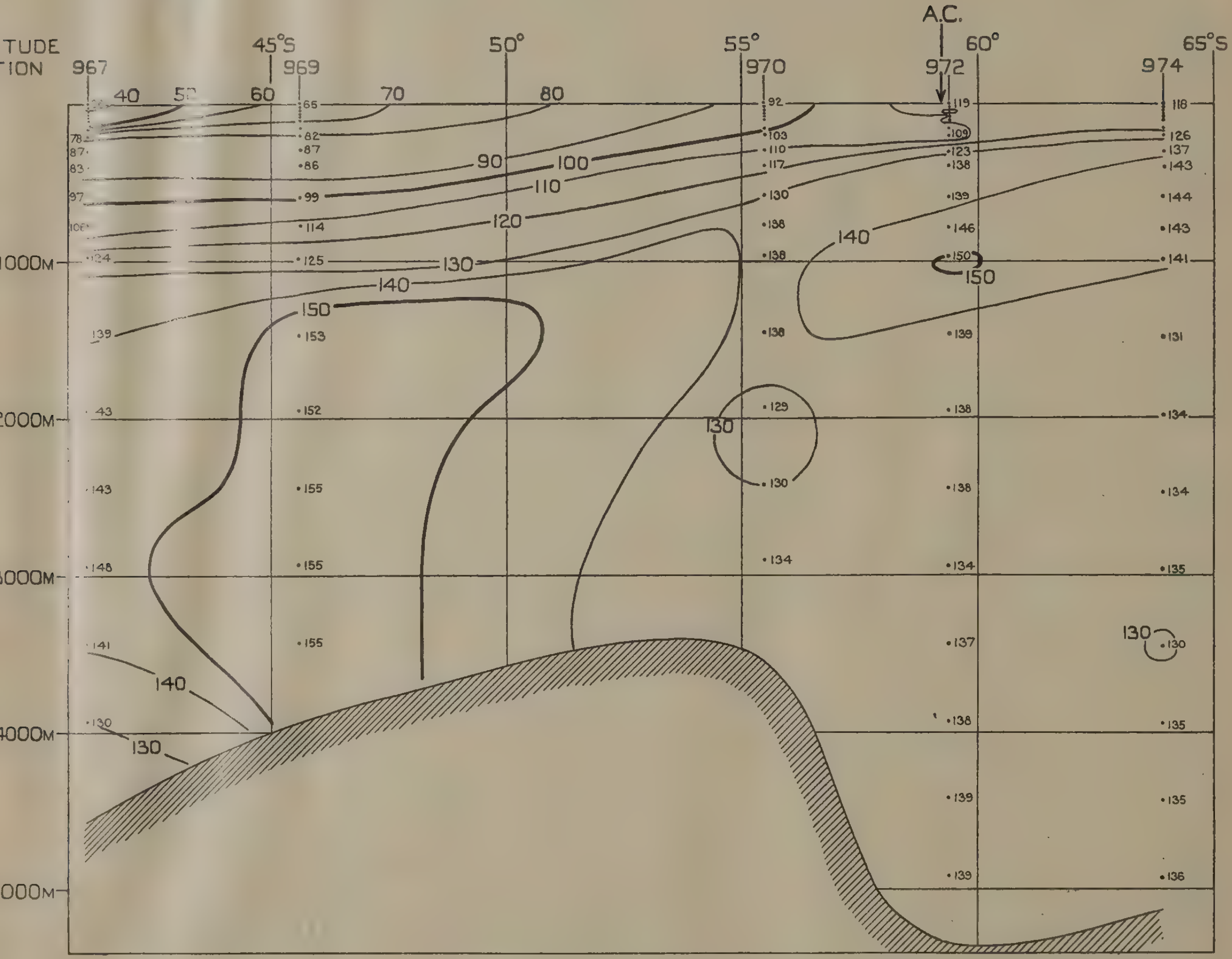
The distribution of silicate along section 13, from the ice-edge in 72° 01′ S, 171° 26′ W, north of the Ross Sea, to Auckland, New Zealand. January 1934.



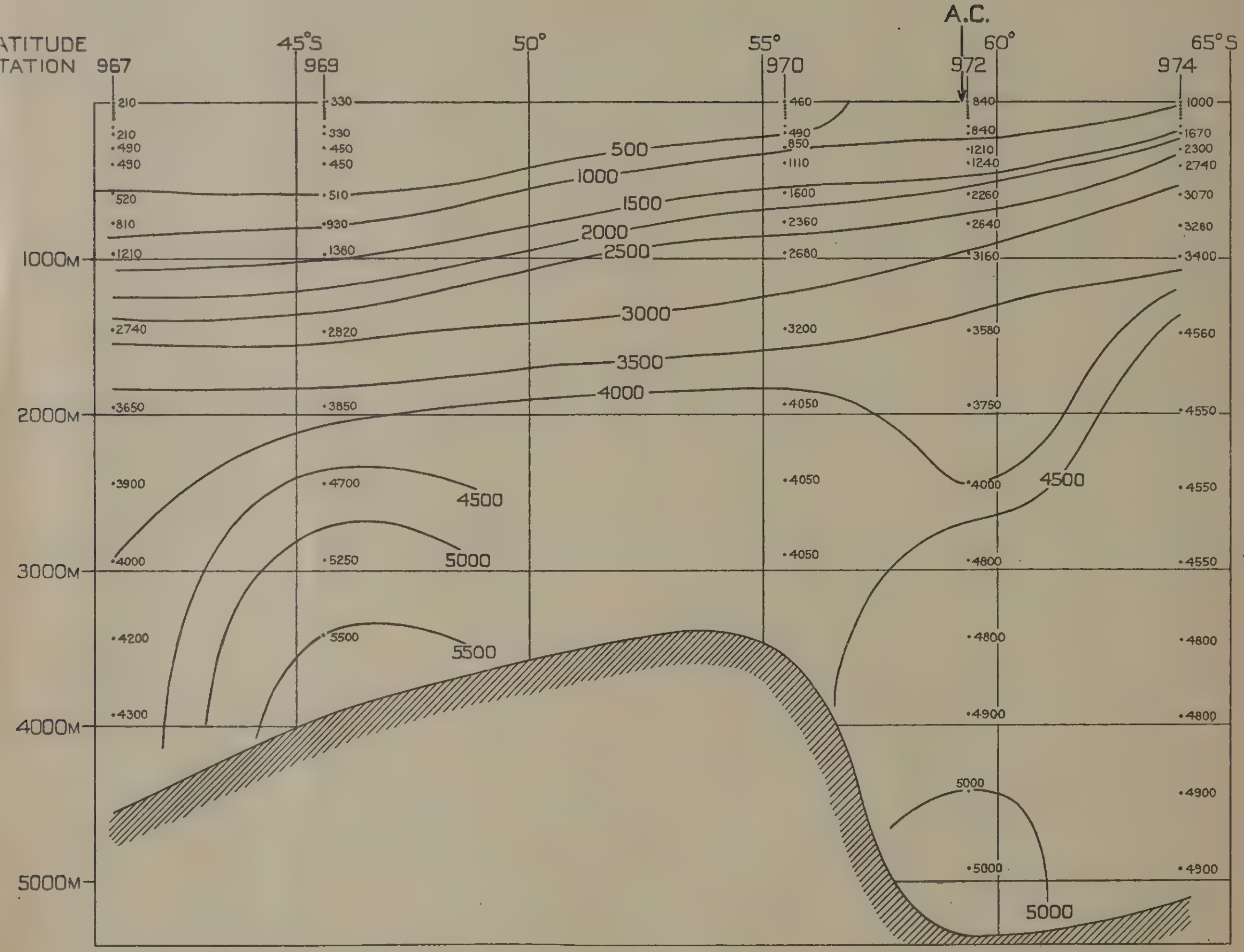
The distribution of phosphate along section 14, from the ice-edge in 61° 07′ S, 153° 57′ W, north of the Ross Sea, to 41° 03′ S, 126° 04′ W, in the central part of the South Pacific Ocean. September 1932.



The distribution of silicate along section 14, from the ice-edge in 61° 07′ S, 153° 57′ W, north of the Ross Sea, to 41° 03′ S, 126° 04′ W, in the central part of the South Pacific Ocean. September 1932.



The distribution of phosphate along section 15, from the end of section 14 in 41° 03′ S, 126° 04′ W to 63° 57′ S, 101° 16′ W. September 1932.



The distribution of silicate along section 15, from the end of section 14 in 41° 03′ S, 126° 04′ W to 63° 57′ S, 101° 16′ W. September 1932.

LATITUDE
STATION

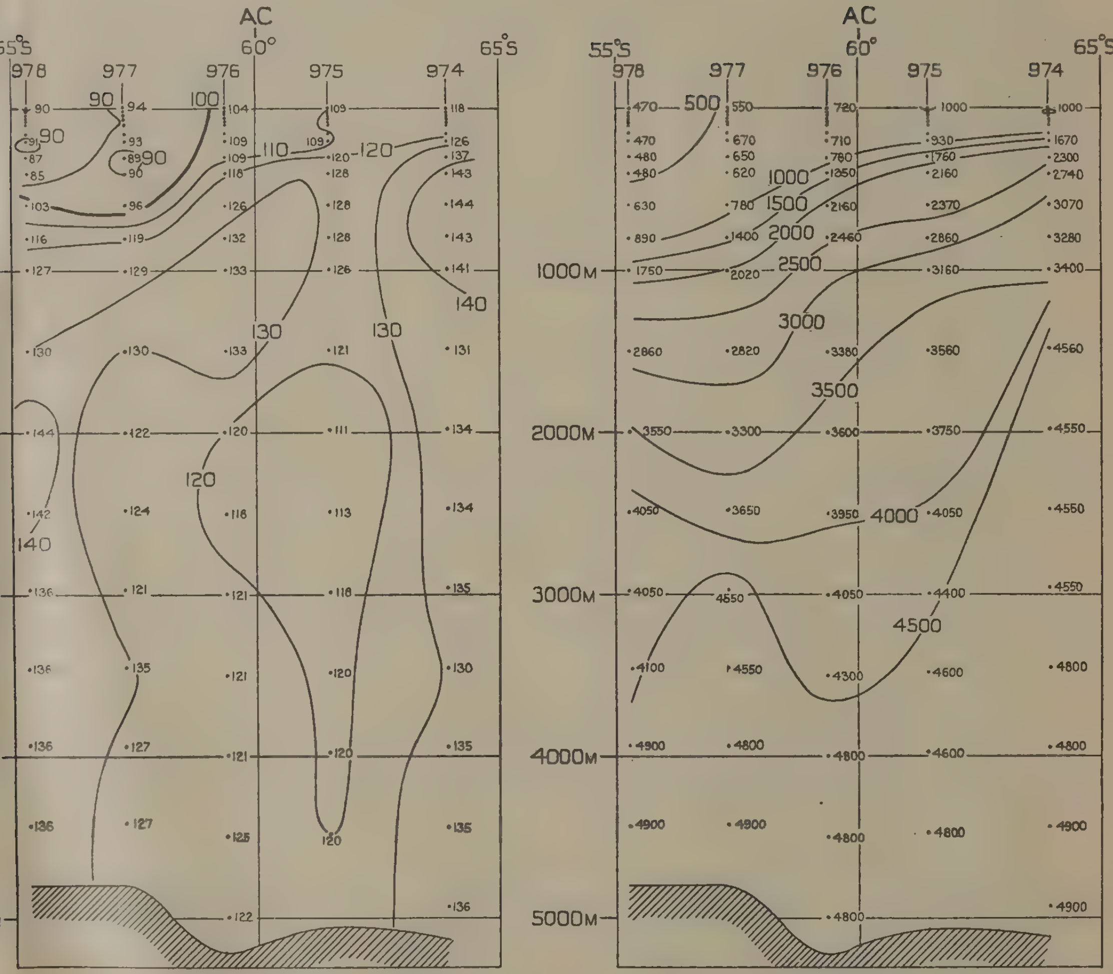
100

200

30

40

50



The distribution of phosphate and silicate along section 16, from 63° 57′ S, 101° 16′ W to the western end of the Magellan Strait. September–October 1932.

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A SECOND REPORT ON THE SOUTHERN SEA LION, *OTARIA BYRONIA* (DE BLAINVILLE)

By

J. E. HAMILTON, M.Sc.

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A SECOND REPORT ON THE SOUTHERN SEA LION, *OTARIA BYRONIA* (DE BLAINVILLE)

By J. E. Hamilton, M.SC.

(Plates XXVI–XXXIII; Text-figs. 1–6)

INTRODUCTION

THE present paper contains the results of a continuation of the research on *Otaria byronia* in the Falkland Islands of which the first report was published in 1934. In it mention was made of five points on which further work was required, namely, length of life, rates of birth, death and increase, oestrous cycle and limits of breeding season, migration and census of the herd in the Falkland Islands.

My sincere thanks are due to the numerous friends in the Falkland Islands who have done so much to facilitate the work, and to the Staff of the British Museum (Natural History) for the numerous occasions on which assistance was given; and, finally, I would express my deep indebtedness to Dr A. S. Parkes, F.R.S., for the great help he has so willingly given in spite of innumerable calls on his time.

During the collection of my first series of sea lions it was observed, in post-mortem examination of the animals killed, that of the three fifth-year cows killed in July although one was pregnant, another had recently aborted and the third had ovulated without becoming obviously pregnant.

Besides this, a sixth year female, killed also in July, contained a large Graafian follicle in one ovary. From these circumstances it was concluded that there must be some sexual activity on the part of the female outside the obvious breeding season in the southern summer.

Since the majority of the cows of suitable age are pregnant in the interval between two breeding seasons, there was reason to expect that if one could discriminate between the gravid and non-gravid animals by inspection it would be possible to make a collection of material from which to work out the sexual history of the species.

I returned to the Falklands in 1933 with the intention of making a census of the herd there and of pursuing the course suggested by the considerations set forth above.

With certain unavoidable interruptions the work was continued until March 1937.

MATERIAL AND METHODS

Since the field work necessitated residence as near as possible to a seal rookery I selected Cape Dolphin on East Falkland, as I was already familiar with it, and erected a standing camp which was supplemented by a turf hut to serve, *inter alia*, as a laboratory.

The principal obstacles to progress were the difficulty, at times, of finding seals suitable for killing and the impossibility of working the same grounds daily, since this would have disturbed the animals too much, and, finally, the necessity of carrying everything to and from the camp on pack horses.

After spending some time watching the winter herd I came to the conclusion that I could discern, by inspection, cows which were not pregnant, owing to their more elegant figures, and experimental killings showed this to be correct, although the matter was complicated by the necessity, from humanitarian reasons, of making every effort not to kill cows which were suckling pups; but such cows usually have mammary glands so well developed that they can be distinguished.

Seventy-two females were collected, and of them 11 were pregnant. The remaining 61 non-pregnant or apparently non-pregnant animals were taken in every month of the year except April and May. When it became obvious that there was a good deal of sexual activity among the cows throughout the year and that it apparently did not always result in pregnancy, in order to ascertain if there were an anoestrous period in the males, a short series of them, 11 in all, was killed, nine of them during what may be termed the "off season", that is, outside the easily recognized breeding season: these bulls were, with one exception (no. 415, see p. 140), the largest which could be found.

The animals were all shot in the brain with a ·22 rifle, using the "long rifle" cartridge; this was in every way satisfactory, since the skull is very little injured and the largest bulls are killed if the bullet is well placed.

After a seal was shot it was always stabbed in the heart, partly as a precaution and partly to reduce the torrents of blood which otherwise pour over and obscure everything when these animals are opened immediately after death. The total length of the animal was measured in as straight a line as possible from the tip of the snout to the end of the tail.

With cows the animal was opened in the midventral line, the ovaries were excised, split to allow access of the fixative and placed in Bouin's aqueous fluid. Segments of the uterine cornua were also fixed and fragments of vagina, etc. when such specimens were indicated. With the males small pieces and sometimes whole testes were fixed. Notes were made on the fresh tissues as requisite. The entire reproductive systems of four cows were collected; one was preserved in spirit and the other three in salt, that is to say, they were covered with dry salt and allowed to make their own brine. After many months these specimens were soaked in repeated changes of fresh water to extract the salt and finally brought up through the alcohols to 70 per cent: they have retained a most agreeable flexibility, and have made exceptionally good material for dissection. The skulls were roughly cleaned and dried for transport, and to each was attached a bone label with a printed number which was connected with every specimen derived from the same animal.

Table I

List of sea lions collected 1934–7 *and considered in this paper. The numbers are written on the skulls and all specimens relating to each animal bear the same number*

Reference no.	Total length cm.	Date of collection	Reference no.	Total length cm.	Date of collection
		Males			
415	213·4	13. i. 36	471	218·4	6. ix. 36
431	246·4	21. iii. 36	479	238·8	1. xii. 36
443	227·3	8. vi. 36	498	213·4	9. x. 34
449	223·5	23. vi. 36	500	226·1	29. viii. 34
464	222·3	7. vii. 36	503	228·6	4. iii. 36
469	213·4	27. viii. 36	"393"	No data	1936*
		Females			
405	175·3	5. xii. 35	480	182·9	14. xii. 36
406	190·5	14. xii. 35	482	157·5	15. xii. 36
407	193·0	17. xii. 35	483	185·4	16. xii. 36
409	177·8	18. xii. 35	489	182·9	21. i. 37
412	185·4	13. i. 36	490	142·2	23. i. 37
414	185·4	13. i. 36	491	162·6	5. ii. 37
417	157·5	23. i. 36	492	170·2	6. ii. 37
419	158·8	24. i. 36	493	160·0	18. ii. 37
421	172·7	2. ii. 36	497	182·9	9. x. 34
422	175·3	6. ii. 36	499	182·9	9. x. 34
423	152·4	7. ii. 36	501	190·5	30. viii. 34
424	175·3	7. ii. 36	502	190·5	30. viii. 34
429	180·3	8. iii. 36	504	185·4	19. ii. 37
430	166·4	9. iii. 36	507	167·6	12. vi. 34
432	174·0	22. iii. 36	508	167·6	25. vi. 34
434	170·2	23. iii. 36	509	146·1	25. vi. 34
436	190·5	22. v. 36	510	170·2	12. vi. 34
439	175·3	25. v. 36	511	149·9	10. ix. 34
440	170·2	26. v. 36	512	139·7	9. vii. 34
441	163·8	6. vi. 36	513	167·6	9. vii. 34
442	160·0	7. vi. 36	514	190·5	9. vii. 34
444	162·6	9. vi. 36	515	175·3	12. vii. 34
445	160·0	9. vi. 36	517	195·6	12. vii. 34
446	162·6	20. vi. 36	518	162·6	4. iii. 37
448	154·3	22. vi. 36	519	180·3	12. ix. 34
450	154·9	24. vi. 36	520	177·8	5. iii. 37
457	157·5	4. vii. 36	521	172·7	21. ix. 34
458	143·7	5. vii. 36	522	177·8	22. ix. 34
465	160·0	9. vii. 36	523	167·6	27. ix. 34
466	160·0	22. viii. 36	525	188·0	27. ix. 34
468	167·6	25. viii. 36	526	193·0	5. xii. 34
470	170·2	5. ix. 36	527	185·4	15. xi. 34
472	171·5	6. ix. 36	529	195·6	11. xii. 34
475	182·9	16. ix. 36	530	168·9	15. xi. 34
477	160·0	28. xi. 36	531	177·8	11. xii. 34
478	193·0	30. xi. 36	532	181·6	5. xii. 34

* Only the scattered skeleton of this animal was found, but the skull was preserved on account of its unusual size.

A few foetuses of moderate size were found, but search for the very early (blastocyst) stages was not feasible in the circumstances.

Bouin's (aqueous) picro-formol has been used for all histological material and has proved exceedingly good, possessing, as it does, great powers of penetration. The subsequent sections were stained with Ehrlich's haematoxylin and eosin, or Weigert's iron haematoxylin followed by van Gieson's picro-säurefuchsin. Histological measurements were made with a micrometer eyepiece.

OSTEOLOGY

MALE SKULL, GIANT SPECIMEN

There are no additional observations to be made on the normal skull of the adult male, but no. "393" calls for some notice (Pl. XXVI).

This specimen, found along with one ramus of the mandible among the scattered bones of the skeleton, was collected on account of its large size and proved to be the largest male skull of which I have a record. The length is 393 mm., the zygomatic width 251 mm. and the hamulo-premaxillar length 285 mm., exceeding the previous maxima of these dimensions by 11·9 and 15 mm. respectively. The crests are of great size, and the whole skull is remarkably massive, weighing 3750 g.; four large skulls in the British Museum weigh 2000–2450 g., with an average of 2200 g.

All the sutures are obliterated, except those of the nasals, the dorsal part of the maxillo-frontals and the junctions of the squamosals and jugals, but the latter are well fused.

The dental part of the premaxillae and maxillae are greatly enlarged by growth of hard cancellous bone, which strongly suggests that it is the result of an inflammatory condition; and of the twelve cheek teeth seven are missing, presumably post-mortem. Two are in moderate condition and three are mere fragments, one of which is partly overgrown with bone; the four middle incisors have all been lost and their alveoli obliterated. The canine of the mandible (right) is very blunt and worn. The remaining teeth are missing, but all of them post-mortem except the first incisor.

Similar proliferation of cancellous bone but on a very limited scale is not uncommon in large males of *Otaria*, and although no preserved material is available for examination it may be suggested that the condition may possibly result from infection which has found an entrance through injuries to the mouth received in fighting, and such injuries are very common.

FEMALE SKULL, DEVELOPMENTAL STAGES OF ADULT LIFE

The series of skulls from sexually active females numbers 93 and covers the period from the first ovulation to what is, almost certainly, senility. Seventy-two of them were collected during the period 1934–7 and 21 belong to the earlier series (1930–2). Since the number of specimens of the sixth year or older is now 58 instead of 11, it is possible to identify age groups additional to those described in 1934, and therefore a revision of the statement made on p. 290 of the report of that date is necessary. Skulls of the fourth to tenth year groups are illustrated in Pls. XXVII, XXVIII and XXIX.

Every month of the year except April is represented, so that it is obvious that these skulls could be arranged to form a continuous and progressive series in which no age groups could be distinguished. In order, therefore, to facilitate the identification of such groups by the creation of gaps in the series corresponding to periods of time the specimens were divided into "summer" and "winter" groups.

"Summer" extends from October to March and includes the breeding season (which may also be a time of least growth owing to preoccupation with reproduction), and "winter" extends from April to September. The division is the more easily made owing to the fortunate absence of specimens taken in April and the presence of only two killed in October, both of them being from animals of advanced age.

Examination of the skulls thus divided has resulted in the distinction of four age groups in addition to those enumerated in 1934, the new groups obviously representing the seventh, eighth, ninth and tenth years of life. The last group must include any animals of more than ten years old, since the skulls in it are in such a condition that it is unlikely that further age groups could be distinguished unless the series were enormously increased, and perhaps not even then, since many of the distinguishing characters (e.g. sutures, by fusion) have by this time achieved a condition of uniformity (1934, p. 290).[1]

The characters which have been used to distinguish the groups are those of size, proportion, both of body and skull, and osteological condition. All of these are subject to considerable individual variation. The condition of the teeth, although providing some indication of advancing age, must only be regarded as supplementary evidence, since the degree of wear varies greatly with the habits of the individual under consideration (Colyer, 1931).

As before, three measurements have been made on each skull: (*a*) The total length from the most anterior projection of the premaxilla to the furthest projection of one of the occipital condyles, usually the left. If the left were damaged, the right was substituted. (*b*) The greatest width across the outside of the zygomatic arch. (*c*) The length from the projection of the premaxilla to the tip of one of the hamular processes. The skull length as a percentage of the body length and the two subsidiary measurements as percentages of the skull length were also calculated: they are displayed in Table II.

The skull of no. 1161, which was not available for examination before, has been included in this series. It has been remeasured and the length is 260 mm. against the 262 mm. previously recorded; the difference may be due to the use of a different instrument, but since it is nearly seven years since the skull was collected it seems possible that it may have shrunk through continuous drying. The difference of 2 mm. is only 0·77 per cent and cannot be regarded as of great importance.

In comparison with the skull of the immature, that of the adult shows an increase in the relative size of the facial region and an alteration of the palate to the elongated and arched form which is accompanied by a downward growth of the ventral plates of

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[1] In order to avoid too lavish recurrence of my name in this paper, references to my previous report are inserted in this fashion.

Table II

Measurements and proportions of skulls

Reference no.	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length
			Males				
415	213·4	316·0	14·8	211·0	66·8	223·5	70·7
431	246·4	331·0	13·4	199·5	60·3	234·0	70·7
443	227·3	313·0	13·8	184·5	58·9	223·0	71·2
449	223·5	322·0	14·4	202·5	62·9	229·0	71·1
464	222·3	324·0	14·6	215·5	66·5	227·0	70·1
469	213·4	301·0	14·1	202·0	67·1	210·0	69·8
471	218·4	322·0	14·7	186·0	57·8	228·0	70·8
479	238·8	334·5	14·1	217·0	64·9	236·0	70·6
498	213·4	310·0	14·5	202·0	65·2	228·0	73·5
500	226·1	321·0	14·2	201·0	62·6	226·5	70·1
503	228·6	314·0	13·7	214·0	68·2	215·0	68·5
"393"	—	393·0	—	251·0	63·9	285·0	72·8
			Females				
405	175·3	255·5	14·6	153·0	59·9	176·0	68·9
406	190·5	262·5	13·8	148·5	56·6	182·0	69·3
407	193·0	257·0	13·3	142·0	55·3	—	—
409	177·8	254·5	14·3	138·5	54·4	171·0	67·2
412	190·5	274·5	14·4	144·5	52·6	186·0	67·8
414	185·4	251·0	13·5	142·5	56·8	167·5	66·7
417	157·5	233·0	14·8	124·0	53·2	157·0	67·4
419	158·8	229·5	14·5	129·5	56·4	148·5	64·7
421	172·7	244·5	14·2	130·0	53·2	164·0	67·1
422	175·3	244·0	13·9	132·5	54·3	164·5	67·4
423	152·4	232·0	15·2	122·0	52·6	152·0	65·5
424	175·3	249·0	14·2	139·5	56·0	—	—
429	180·3	260·0	14·4	146·0	56·2	179·0	68·8
430	166·4	248·5	14·9	126·5	50·9	162·5	65·4
432	174·0	255·0	14·7	132·5	52·0	172·5	67·6
434	170·2	253·5	14·9	139·0	54·8	169·0	66·7
436	175·3	269·0	14·1	144·0	53·5	187·5	69·7
439	175·3	244·5	13·9	143·5	58·7	163·5	66·9
440	170·2	260·0	15·3	132·5	51·0	175·5	67·5
441	163·8	244·5	14·9	126·5	51·7	167·0	68·3
442	160·0	235·0	14·7	130·0	55·3	160·0	68·1
444	162·6	239·0	14·7	127·5	53·3	160·0	66·9
445	160·0	236·0	14·8	122·0	51·7	161·0	68·2
446	162·6	242·0	14·9	131·5	54·3	—	—
448	154·3	245·0	15·9	130·5	53·3	162·0	66·1
450	154·9	233·5	15·1	121·0	51·8	151·0	64·7
457	157·5	247·5	15·7	130·5	52·7	167·5	67·7
458	147·1	232·5	15·8	120·0	51·6	151·0	64·9
465	160·0	237·5	14·8	127·5	53·7	158·5	66·7
466	160·0	243·0	15·2	129·0	53·1	162·5	66·9
468	167·6	241·0	14·4	127·0	52·7	160·0	66·4

Table II (*contd*)

Reference no.	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length
			Females				
470	170·2	239·5	14·1	134·0	55·9	157·5	65·8
472	171·5	253·5	14·8	136·0	53·6	173·5	68·4
475	182·9	264·0	14·4	151·0	57·2	179·0	67·8
477	160·0	234·0	14·6	126·0	53·8	159·0	67·9
478	193·0	263·0	13·6	159·0	60·5	183·5	69·8
480	182·9	266·0	14·5	158·0	59·4	178·5	67·1
482	157·5	230·0	14·6	127·5	55·4	155·5	67·6
483	185·4	264·0	14·2	152·0	57·6	187·0	70·8
489	182·9	263·5	14·4	136·5	51·8	182·0	69·1
490	142·2	228·0	16·0	120·0	52·6	152·0	66·7
491	162·6	240·0	14·8	129·5	54·0	157·0	65·4
492	170·2	251·0	14·7	133·0	53·0	168·0	66·9
493	160·0	239·5	15·0	130·0	54·3	162·5	67·8
497	182·9	272·5	14·9	155·0	56·9	188·0	69·0
499	182·9	272·0	14·9	156·5	57·5	189·5	69·7
501	190·5	274·0	14·4	154·0	56·2	185·5	67·7
502	190·5	276·0	14·5	155·0	56·2	189·0	68·5
504	185·4	261·0	14·1	142·0	54·4	177·0	67·8
507	167·6	251·0	15·0	129·5	51·6	165·5	65·9
508	167·6	253·5	15·1	139·5	55·0	169·5	66·9
509	149·1	224·0	15·3	126·0	56·3	145·5	65·0
510	170·2	231·0	13·6	123·5	53·5	152·5	66·0
511	149·9	233·5	15·6	125·0	53·5	155·0	66·4
512	139·7	229·0	16·4	121·0	52·8	149·0	65·1
513	167·6	240·0	14·3	129·0	53·8	157·5	65·6
514	190·5	269·5	14·2	152·0	56·4	183·5	68·1
515	172·3	247·5	14·4	126·0	50·9	169·5	68·5
517	195·6	272·0	13·9	155·0	57·0	190·0	69·9
518	162·6	238·0	14·6	127·0	53·4	159·5	67·0
519	180·3	260·0	14·4	153·5	59·0	182·0	70·0
520	177·8	251·5	14·1	133·5	53·1	168·0	66·8
521	172·7	258·0	14·9	150·0	58·1	175·0	67·8
522	177·8	255·5	14·4	143·5	56·2	173·5	67·9
523	167·6	242·5	14·5	137·0	56·5	164·5	67·8
525	188·0	264·0	14·0	147·5	55·9	179·0	67·8
526	193·0	263·5	13·7	143·0	54·3	—	—
527	185·4	273·5	14·8	151·5	55·4	189·0	69·1
529	195·6	263·5	13·5	147·0	55·8	183·0	69·4
530	168·9	245·5	14·5	129·0	52·5	163·0	66·4
531	177·8	251·0	14·1	141·5	56·4	—	—
532	181·6	272·0	15·0	155·5	57·2	187·5	68·9
1161	187·9	260·0	13·8	145·0	55·8	178·0	68·5

Table III

Measurements and proportions of female skulls in age groups

Reference no.	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length
Fourth year							
1056	137·1	224·0	16·3	115·0	51·3	139·0	62·1
512	139·7	229·0	16·4	121·0	52·8	149·0	65·1
1098	142·2	220·0	15·5	117·0	53·2	137·0	62·3
1179	142·2	223·0	15·7	120·0	53·8	147·0	65·9
1023	142·2	223·0	15·7	117·0	52·5	136·0	61·0
490	142·2	228·0	16·0	120·0	52·6	152·0	66·7
509	142·1	224·0	15·3	126·0	56·3	145·5	65·0
458	147·3	232·5	15·8	120·0	51·6	151·0	64·9
511	149·9	233·5	15·6	125·0	53·5	155·0	66·4
1016	151·0	232·0	15·4	121·0	52·2	154·0	65·5
423	152·4	232·0	15·2	122·0	52·6	152·6	65·5
450	154·9	233·5	15·1	121·0	51·8	151·0	64·7
417	157·5	233·0	14·8	124·0	53·2	157·0	67·4
419	158·8	229·5	14·5	129·5	56·4	148·5	64·7
Fifth year							
1030	153·6	231·0	15·0	128·0	55·4	150·0	64·9
448	154·3	245·0	15·9	130·0	53·3	162·0	66·1
1001	157·4	228·0	14·5	126·0	55·3	155·0	68·0
1100	157·4	235·0	14·9	131·0	55·7	152·0	64·7
1167	157·4	242·0	15·4	130·0	53·7	157·0	64·9
482	157·5	230·0	14·6	127·5	55·4	155·5	67·6
457	157·5	247·5	15·7	130·5	52·7	167·5	67·7
477	160·0	234·0	14·6	126·0	53·8	159·0	67·9
442	160·0	235·0	14·7	130·0	55·3	160·0	68·1
445	160·0	236·0	14·8	122·0	51·7	161·0	68·2
465	160·0	237·5	14·8	127·5	53·7	158·5	66·7
493	160·0	239·5	15·0	130·0	54·3	162·5	67·8
466	160·0	243·0	15·5	129·0	53·1	162·5	66·9
518	162·6	238·0*	14·6	127·0	53·4	159·5	67·0
444	162·6	239·0	14·7	127·5	53·3	160·0	66·9
491	162·6	240·0	14·8	129·5	54·0	157·0	65·4
446	162·6	242·0	14·9	131·5	54·3	—	—
1175	165·0	237·0	14·4	127·0	53·4	157·0	66·2
513	167·6	240·0	14·3	129·0	53·8	157·5	65·6
468	167·6	241·0	14·4	127·0	52·7	160·0	66·4
510	170·2	231·0	13·6	123·5	53·5	152·5	66·0
470	170·2	239·5	14·1	134·0	55·9	157·5	65·8

* The condyles of no. 518 were both damaged by the bullet but that from which the measurement was taken was estimated to have lost only 1·0 mm.

Table III (*contd*)

Reference no.	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length
Sixth year							
1065	160·0	247·0	15·4	132·0	53·4	164·0	66·4
441	163·8	244·5	14·9	126·5	51·7	167·0	68·3
430	166·4	248·5	14·9	126·5	50·9	162·5	65·4
523	167·6	242·5	14·5	137·0	56·5	164·5	67·8
507	167·6	251·0	15·0	129·5	51·6	165·5	65·9
508	167·6	253·5	15·1	139·5	55·0	169·5	66·9
530	168·9	245·5	14·5	129·0	52·5	163·0	66·4
492	170·2	251·0	14·7	133·0	53·0	168·0	66·8
434	170·2	253·5	14·9	139·0	54·8	169·0	66·7
472	171·5	253·5	14·8	136·0	53·6	173·5	68·4
515	175·3	247·5	14·4	126·0	50·9	169·5	68·5
421	172·7	244·5	14·2	130·0	53·2	164·0	67·1
1168	172·7	247·0	14·3	135·0	54·7	169·0	68·4
432	174·0	255·0	14·7	132·5	52·0	172·5	67·6
422	175·3	244·0	13·9	132·5	54·3	164·5	67·4
439	175·3	244·5	13·9	143·5	58·7	163·5	66·9
424	175·3	249·0	14·2	139·5	56·0	—	—
520	177·8	251·5	14·1	133·5	53·1	168·0	66·8
Seventh year							
440	170·2	260·0	15·3	132·5	51·0	175·5	67·5
1129	170·1	247·0	14·5	135·0	54·7	168·0	68·0
1122	177·7	248·0	14·0	138·0	55·6	177·0	71·4
531	177·8	251·0	14·1	141·5	56·4	—	—
522	177·8	255·5	14·4	143·5	56·2	173·5	67·9
429	180·3	260·0	14·4	146·0	56·2	179·0	68·8
1137	182·8	253·0	13·8	144·0	56·9	165·0	65·2
489	182·9	263·5	14·4	136·5	51·8	182·0	69·1
414	185·4	251·0	13·5	142·5	56·8	167·5	66·7
504	185·4	261·0	14·1	142·0	54·4	177·0	67·8
406	190·5	262·5	13·8	148·5	56·6	182·0	69·3
Eighth year							
409	177·8	254·5	14·3	138·5	54·4	171·0	67·2
1149	180·3	264·0	14·6	142·0	53·8	178·0	67·4
475	182·9	264·0	14·4	151·0	57·2	179·0	67·8
483	185·4	264·0	14·2	152·0	57·6	187·0	70·8
1161	187·9	260·0	13·8	145·0	55·8	178·0	68·5
526	193·0	263·5	13·7	143·0	54·3	—	—

Table III (*contd*)

Reference no.	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length
Ninth year							
521	172·7	258·0	14·9	150·0	58·1	175·0	67·8
436	190·5	269·0	14·1	144·0	53·5	187·5	69·7
407	193·0	257·0	13·3	142·0	55·3	—	—
529	195·6	263·5	13·5	147·0	55·8	183·0	69·4
Tenth year and over							
405	175·3	255·0	14·6	153·0	59·9	176·0	68·9
1131	177·7	255·0	14·4	146·0	57·3	175·0	68·6
519	180·3	260·0	14·4	153·5	59·0	182·0	70·0
532	181·6	272·0	15·0	155·5	57·2	187·5	68·9
1132	182·3	254·0	13·9	139·0	54·7	172·0	67·7
480	182·9	266·0	14·5	158·0	59·4	178·5	67·1
499	182·9	272·0	14·9	156·5	57·5	189·5	69·7
497	182·9	272·5	14·9	155·0	56·9	188·0	69·0
527	185·4	273·5	14·8	151·5	55·4	189·0	69·1
525	188·0	264·0	14·0	147·5	55·9	179·0	67·8
1104	190·4	260·0	13·5	145·0	55·8	179·0	68·8
1114	190·4	267·0	14·0	151·0	56·6	180·0	67·4
514	190·5	269·5	14·2	152·0	56·4	183·5	68·1
412	190·5	274·5	14·4	144·5	52·6	186·0	67·8
501	190·5	274·0	14·4	154·0	56·2	185·4	67·7
502	190·5	276·0	14·5	155·0	56·2	189·0	68·5
478	193·0	263·0	13·6	159·0	60·5	183·5	69·8
517	195·6	272·0	13·9	155·0	57·0	190·0	69·9

the pterygoids. The zygomatic arch becomes more massive and the squamosal part of it tends to approach nearer the horizontal, and in the oldest skulls is fused to the maxillary process. The temporal lines approach one another and lie side by side for most of their length in the majority of the oldest skulls, but they are occasionally somewhat separated in the parietal region. Crests for the attachment of the jaw muscles are always more or less developed, but to a degree which is subject to great variation. There is a general increase in the massiveness and rugosity of the skull and a progressive fusion of the cranial sutures.

Grouping of specimens such as these can only be made by the use of comparative methods; the descriptions have, therefore, been written principally with reference to conditions occurring in preceding age groups, since this is a series of specimens of increasing age. As I am not concerned with animals before they are sexually active, and have no fresh material from them, reference should be made to the previous paper for data pertinent to the first three annual groups.

Summary of observations on age groups of the female skull

The measurements given in the following paragraphs are averages. Since there is invariably an increase in size it is not remarked on; the figures are given in Table IV.

FOURTH YEAR. Fourteen winter specimens, total length 228·4 mm., 15·5 per cent of the body length; zygomatic width 121·3 mm., hamulo-premaxillar length 148·0 mm., 53·1 and 64·8 per cent of the skull length. The rounded outline is still somewhat reminiscent of the immature skull and the facial region is less conspicuous than in later stages. The vertical part of the palatine is still rather narrow and a short length of the lambdoidal suture about the level of the parieto-mastoid suture is unfused. The canines are usually small and the transverse groove in the edge of the incisors is still deep in most specimens, or if worn is easily seen (see also 1934, p. 289).

Table IV

Average measurements and proportions of annual age groups (Females)

Year of age	Total length cm.	Skull length mm.	Skull length as % of body length	Zygomatic width mm.	Zygomatic width as % of skull length	Hamulo-premaxillar length mm.	Hamulo-premaxillar length as % of skull length	No. of specimens
IV	147·4	228·4	15·5	121·3	53·1	148·0	64·8	14
V	161·2	237·8	14·8	128·3	54·0	158·3	66·6	22
VI	170·5	248·5	14·6	133·4	53·7	166·9	67·2	18
VII	180·1	255·7	14·2	140·9	55·1	174·7	68·2	11
VIII	184·6	261·7	14·2	145·3	55·1	178·6	68·3	6
IX	188·0	261·9	14·0	145·8	55·7	181·8	69·0	4
X and over	186·2	266·7	14·3	151·7	56·9	182·9	68·9	18

FIFTH YEAR. Twenty-two winter specimens, total length 237·8 mm., 14·8 per cent of the body length; zygomatic width 128·3 mm., hamulo-premaxillar length 158·3 mm., 54·0 and 66·6 per cent of the skull length. The skull shows a distinct approach to the adult character. The facial part has a relative increase in importance, the temporal lines almost meet anteriorly, and indications of the development of bony crests for the attachment of the jaw muscles may appear. The palate is more elongated and the vertical part of the palatine is relatively deeper and better ossified than in the fourth year. The hamular processes are more oblique and in their increased length approach the adult condition. There is usually still visible a vestige of the lambdoidal suture at the level of the parieto-mastoid suture. The upper incisors frequently show signs of wear, but not to such an extent as to obliterate the transverse grooves.

SIXTH YEAR. Eighteen winter specimens, total length 248·5 mm., 14·6 per cent of the body length; zygomatic width 133·4 mm., hamulo-premaxillar length 166·9 mm., 53·7 and 67·2 per cent of the skull length. The principal alteration appears in the form of a forward and usually slightly downward growth of the premaxilla and the canine part of the maxilla, so that the anterior part of the upper jaw alters its position with reference to the line of the cheek teeth and at the same time becomes more emphasized. The temporal lines are closer together than they are in the fifth year, the sagittal suture has become extremely complex and is beginning to show signs of fusion and supervening obliteration from behind forward.

In some of the summer skulls of this year the sagittal suture has disappeared and the mastoid part of the periotic has begun to fuse with the cranium.

SEVENTH YEAR. There are only two skulls which can be placed in the winter group of this year; the description, therefore, has been based on the slightly more advanced skulls of the summer, although this increases the time interval between them and the sixth year winter specimens. Eleven summer specimens, total length 255·7 mm., 14·2 per cent of the body length; zygomatic width 140·9 mm., hamulo-premaxillar length 174·7 mm., 55·1 and 68·2 per cent of the skull length. These skulls are definitely more massive and the ridges which mark the origin of the jaw muscles begin to be conspicuous. The sagittal suture is entirely or almost entirely fused, and the coronal suture begins to disappear from the middle line outwards. The sutures between the mastoid part of the periotic and the cranium are usually partly obliterated. The palate is usually more deeply excavated at the level of the zygomatic processes of the maxillae than it is in the sixth year.

EIGHTH YEAR. Six specimens, total length 261·7 mm., 14·2 per cent of the body length; zygomatic width 145·3 mm., hamulo-premaxillar length 178·6 mm., 55·1 and 68·3 per cent of the skull length. Apart from increase in size and massiveness the principal differences between this group and that which precedes it are to be found in the more advanced state of sutural fusion. Besides further progress in the fusion of the sutures mentioned under the seventh year, the palato-pterygoidal sutures begin to disappear and sometimes the squamosal as well. All summer specimens.

NINTH YEAR. There are four skulls, all collected in summer and of large size which, not having yet reached the condition of the final group, show nevertheless an advance on the state of the eighth year. These must be regarded as forming a ninth year group in which a further advance in average size is accompanied by still more complete fusion of the bones of the skull. Four specimens, total length 261·9 mm., 14·0 per cent of the body length; zygomatic width 145·8 mm., hamulo-premaxillary length 181·8 mm., 55·7 and 69·0 per cent of the skull length.

The coronal sutures as well as the sagittal are usually obliterated. The squamosal is fused to the parietal and to the alisphenoid and the latter to the frontal. The orbitosphenoid and the alisphenoid are also united and the pterygoids and palatines are fused.

TENTH YEAR AND OVER. Eighteen specimens, total length 266·7 mm., 14·3 per cent of the body length; zygomatic width 151·7 mm., hamulo-premaxillar length 182·9 mm., 56·9 and 68·9 per cent of the skull length. This final group includes 18 which have all well-fused sutures and with one exception, no. 502, well-developed muscular crests. The projection of the pterygoids below the level of the alveolar ridges is conspicuous;

the jugal is fused to the zygomatic process of the maxilla and the line of fusion becomes obliterated. The teeth show marked wear and the canines are conspicuous for their length; but the pulp cavity is still open in the canines of two skulls at least—nos. 478 and 480.

The average size of this group with regard both to the length of the body and length and other dimensions of the skull is greater than in any other group, and I have never seen cows which could reasonably be supposed to be larger than in these animals. It may therefore be asserted that the tenth year group includes animals of the maximum size for the female of *Otaria byronia*. The greatest body length is 195·6 cm., and the greatest skull length 276 mm. It is a peculiar fact that in some of these skulls the floor of the *sella turcica* becomes of almost paper thinness.

The approximation to a normal growth curve of the graph in Fig. 1 may be observed.

REPRODUCTION

ANATOMY OF THE REPRODUCTIVE ORGANS

Male. The anatomy of the reproductive system of the male has been fully described by Murie (1874) and need not be remarked on here except to state that he found that the prostate is small and Cowper's glands, if present, are little more than vestigial. His specimen was an immature male, presumably in its fourth year and 170 cm. in length.

Female. The ovaries have a rounded bean shape and increase in size with advancing age (Fig. 3). The increase is not necessarily due to the presence of corpora lutea, although there is almost invariably a structure of that nature present in one or other of the ovaries. There is an actual increase in the amount of ovarian stroma, due, it may be suggested, to previous activity. The surface is quite smooth in the young animal, e.g. no. 450, and becomes very slightly pitted with advancing age. The smallest pair of ovaries is that of no. 458, with weights of 3·5 and 2·5=6 g., and the largest pair from a non-pregnant cow are those of no. 478, 31 and 28=59 g. Even when ripe the follicle does not project appreciably from the surface of the ovary, but its presence is indicated by a darkening of the wall at the place where rupture will take place, and the thinning of the tissues enables the follicular fluid to become perceptible (the macula).

When the corpus luteum is formed it does not project from the surface, but the entire ovary is enlarged by its presence; the smooth surface of the ovary is maintained. Corpora lutea disappear fairly rapidly; in the whole series two are present in but six cases and in only three others can the traces of a third be found (p. 144).

Seal no. 510, which contained male twins, had two corpora lutea of pregnancy in the appropriate side and in the other ovary was an old corpus luteum about 1 cm. in longest diameter. The size of the largest corpus luteum in each animal is shown in Table VIII; the figures are those of the longest diameter, but these bodies are not usually exactly spherical.

The ovary is enclosed in a capsule which communicates with the body cavity by a small aperture, but immediately after ovulation the capsule is filled with *liquor folliculi* so that at least at this period the aperture is almost or entirely non-functional.

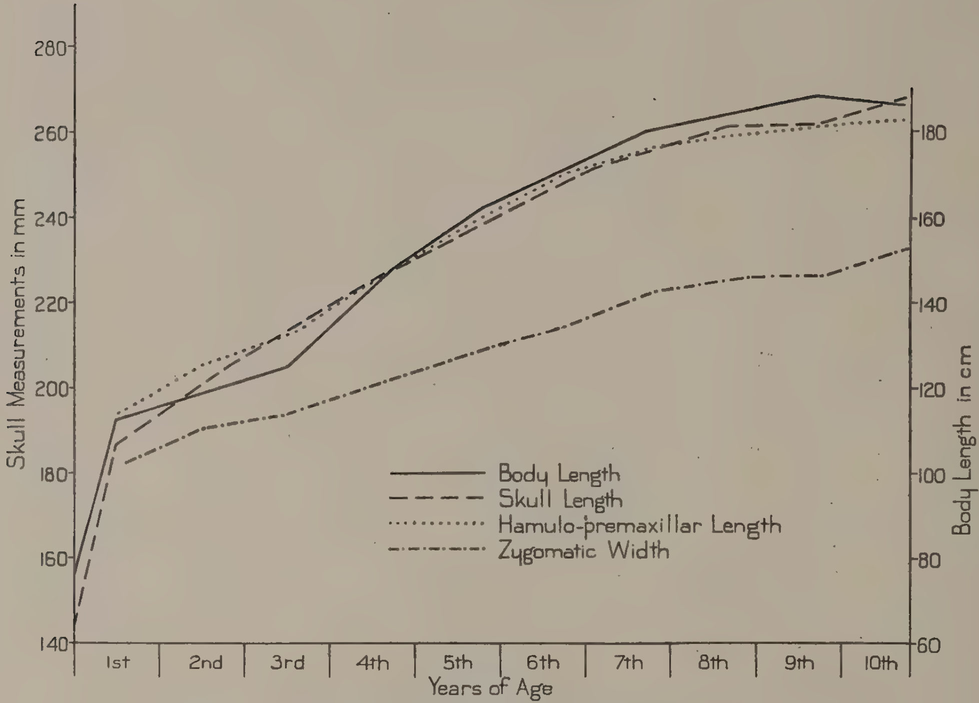

Fig. 1. Females. Average increase with growth in measurements of body and skull. Compare with (1934) fig. 5.

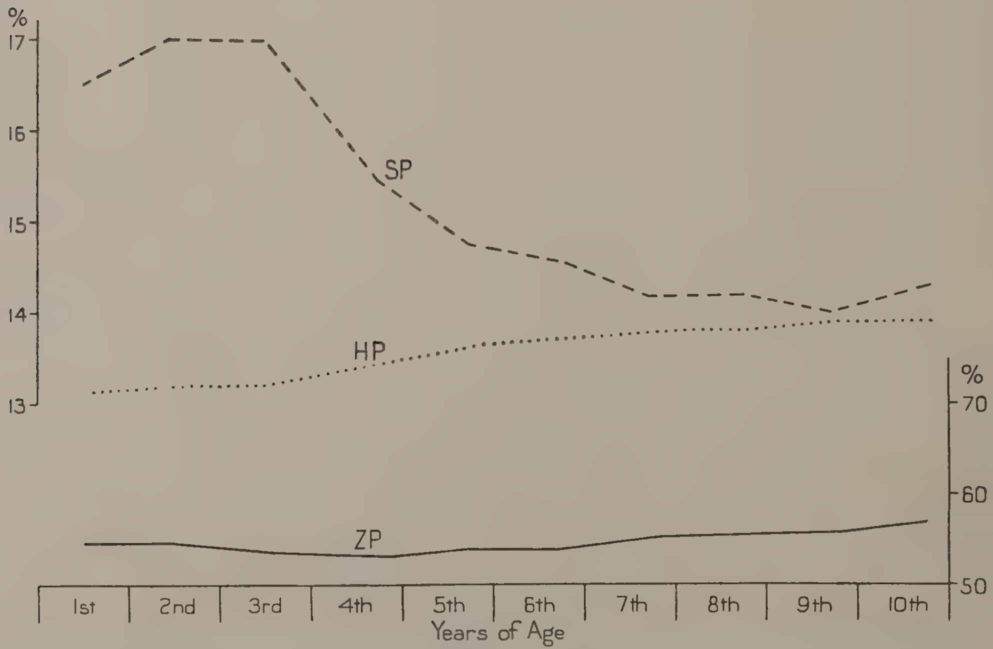

Fig. 2. Variations in proportion during growth. *S.P.*, skull length as percentage of body length; *H.P.* hamulo-premaxilla length as °/₀ of skull length; *Z.P.*, Zygomatic width as °/₀ of skull length. Compare with (1934) fig. 6.

The uterus is bicornuate and the lumina of the horns are discrete for almost their entire length uniting at a point only 2 or 3 cm. from the os uteri. In no. 477 they do not unite at all but enter the vagina by separate apertures. The external walls of the cornua unite in the middle line about the middle of their length.

The following description and measurements are taken from the reproductive system of no. 475, which was a large animal (see Plate XXX).

The abdominal aperture of the Fallopian tube is situated laterally and dorsally with reference to the ovary; it is of small size and surrounded by the delicate and irregular fimbria which, although somewhat extensively adherent to the interior of the ovarian capsule, may, in places, have a free height of 1·5 cm.; but as has been said it is very irregular in form. The abdominal aperture readily admits a blunt seeker but the uterine end of the tube is too small to allow this. The tube follows a tortuous course in the wall of the capsule ventral to the ovary, turning eventually in a dorsal direction and bending slightly towards the middle line before opening into the uterus by a funnel-shaped mouth. The length of the Fallopian tube is about 21 cm., but owing to its sinuous form it is not possible to measure it with precision.

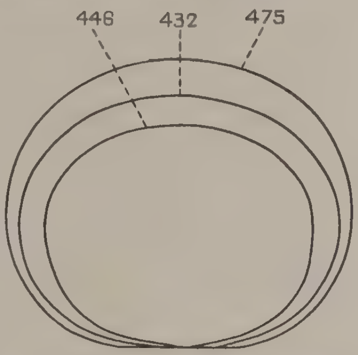

Fig. 3. Diagram of right ovaries of 446, 432, 475, showing relative increase from non-parous to multiparous condition.

The right cornu of no. 475 is 27·5 cm. in length and the mucosa is deeply folded longitudinally; but in a non-parous animal the folds were less deep. At a distance of about a centimetre from the aperture of the Fallopian tube the wall of the cornu, excluding the mucous membrane, is 0·25 cm. thick, and at a similar distance from the junction of the cornua the thickness is about 1 cm. The common part of the uterus is only 3·1 cm. in length, little more than the length of the cervix, which projects into the vagina for a distance of 2·2 cm. and is curved sharply downwards so that the os uteri opens almost ventrally.

The vagina is 8 cm. long from the sulcus which surrounds the cervix uteri to the hymeneal fold which separates the vagina from the vestibule. Its walls are smooth and almost devoid of longitudinal folding, thus contrasting with both the cornua and the vestibule.

The hymeneal fold is a structure which runs round the wall of the passage and is reminiscent of the folds found in a corresponding site in *Balaenoptera*. Its maximum height in no. 475 is 2 mm.

The vestibule is 4·9 cm. in length and terminates at the level of the clitoris where the integument begins to show signs of pigmentation, but there is an almost complete absence of hairs for another 4 cm. when the sharply marked edge of the coat is reached. The vestibule contains the urethral aperture, which is about 5 mm. long and situated on a papilla slightly to the right of the middle line and rather more than a centimetre from the hymeneal fold.

The clitoris is about 1 cm. in height and conical, with the point directed almost dorsally. It is surrounded ventrally and posteriorly by a horseshoe-shaped elevation which represents the labia minora and their anterior commissure.

The whole length of the genital passage from the abdominal aperture of the Fallopian tube to the clitoris is 60 cm., allowance having been made for duplication of the length of the cervix when the parts are considered serially. (These measurements were made on the preserved specimen.)

No. 475 was in its eighth year and had a length of 182·9 cm., and a comparison with the organs of no. 446 (fifth year, 162·6 cm.) and no. 432 (sixth year, 174 cm.) show certain differences which must be attributed to less age and less prolonged sexual experience (Table V). The ovaries show a progressive enlargement in accordance with the increase in the size of the animal, as has been said. It was unfortunately impossible to measure the thickness of these organs in no. 475 or to weigh them, because pieces had to be cut out for fixation in the field.

Table V. *Dimensions of the female reproductive organs*

Reference no.	Year of age	Body length cm.	Length of cornu cm.	Thickness of cornua cm.	Length of vagina cm.	Length of vestibule cm.	Weight g.	Size, right ovary cm.
446	5th	162·6	14·5	1·1 1·1	6·5	7	241	2·9 × 2·5
432	6th	174·0	17·0	1·25 1·8	8·0	7	312	3·5 × 2·8
475	8th	182·9	27·5	2·6 2·6	8·0	6	652	3·8 × 3·2

In the interval (about three years) covered by growth from the size of no. 446 to that of no. 475 the cornua nearly double their length and more than double their thickness; the vagina increases slightly in length but the vestibule is a little shorter in no. 475.

The hymeneal fold is much more conspicuous in both the younger animals and the digitations better developed, reaching a height of 2 cm. in no. 446. The possession of such appendages cannot, however, be regarded as a sign of youth. I have observed that there is a great variation in this condition. In no. 407 the digitations were particularly large and this cow was 193 cm. in length, one of the largest killed.

In the two younger animals the walls of the common passage are more compact and much more deeply folded than in no. 475, where the vaginal walls were almost smooth; the vestiges of the labia minora surrounding the clitoris are markedly better developed. As might be expected the differences are most conspicuous in no. 446.

These progressive changes are those which one would expect to be produced by the transition from the non-parous to the parous and finally the multiparous state. Since no. 475 was so large a cow she was certainly multiparous, and since no. 432 had a little milk in the glands she was also parous, probably in the preceding breeding season.

No. 446, however, had very small ovaries, short and slender cornua and a small and apparently unstretched common passage as well as comparatively small body size. There was, moreover, no trace of milk and, at a time (June) when pregnant cows have foetuses several centimetres in length which cannot escape observation, there was no suspicion of the presence of a foetus. It is, therefore, my opinion that no. 446 was non-parous, and almost certainly a virgin in an advanced stage of pseudo-pregnancy.

Note on measurements of ovaries and uteri. Fixation usually causes the muscles of the living uterus to contract. It has therefore not been considered advisable to measure the thickness of the uterine stroma. But since it was considered desirable to make some comparison of the sizes of the uteri the entire segments were measured for outside diameter with callipers which read to 0·5 mm. and the result is shown in Fig. 4 against the total length of the animals. It was observed during collection that there was a great difference in size of the ovaries. They have therefore been weighed and their weight as well as the outside diameter of the cornua has been found to vary approximately with the size of the animals from which they were procured, that is, with age (Fig. 5). In making these comparisons, cornua of pregnant cows were omitted, and cornua showing obvious post-partum enlargement were also shut out. Test plotting, in which oestrous and post-ovulation specimens were differentiated, showed no significant correlations. Table VII shows the figures resulting from the measurements.

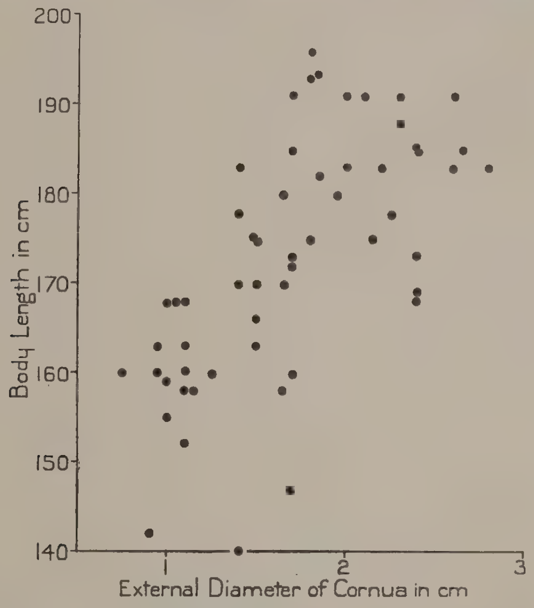

Fig. 4. Body length and average thickness of cornua. 57 non-pregnant females.

OESTRUS, IN THE MALE

In order to ascertain if there is an anoestrous season in the male 11 bulls were killed to provide material for microscopic examination. These animals varied from 213·4 to 246·4 cm. in length and were with one exception the largest males I could find at the time of collection. The exception was no. 415, which is one of the smallest animals of this series; but it was of quite exceptional ferocity and had indeed to be killed because its repeated and furious attacks prevented me from approaching a cow which I had shot. The cow had just been covered by this bull and sections of his testis and epididymis show abundance of spermatozoa, so that it is quite clear that in spite of his relatively small size this was an animal in fullest sexual activity. I have observed on other occasions that it is not always the largest males which are the most successful.

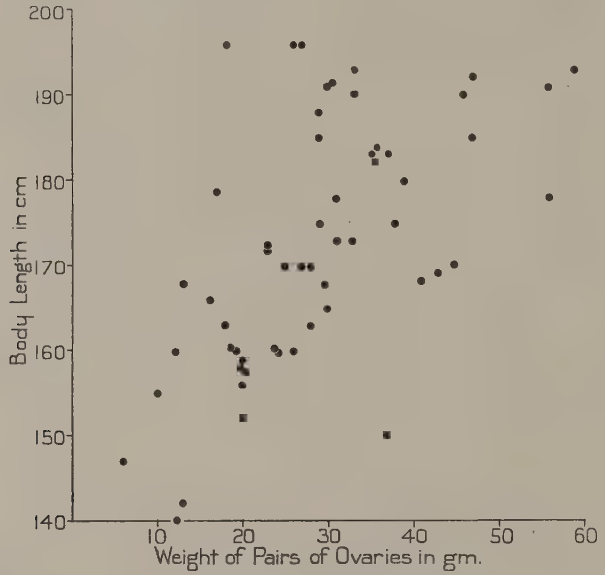

Fig. 5. Body length and weight of pairs of ovaries. 56 non-pregnant females.

Data referring to the genitalia are shown below in Table VI, arranged in chronological order form March to January, that is, from after one breeding season to the peak of the next.

Table VI

Reference no.	Date	Length of testis cm.	Diameter of testis cm.	Combined weight g.	Sperms in epididymis
503	4. iii	6·4	3·2	—	Nil
431	21. iii	7·6	2·5	—	Nil
443	8. vi	6·4	3·5	84	Plentiful
449	23. vi	6·7	3·5	111	Nil, but many in vas deferens
464	7. vii	6·1	2·8	75	Very few
469	27. viii	6·6	3·0	79	Present
500	29. viii	—	3·2	—	Mostly empty, a few tube sections with many
471	6. ix	6·8	3·3	96	Plentiful
498	9. x	—	3·1	—	Abundant
479	1. xii	7·6	4·0	—	Plentiful
415	13. i	—	3·5	—	Plentiful

Table VII

Record of the weights and measurements of non-pregnant or apparently non-pregnant females (*see p.* 139)

Reference no.	Weight		Diameter		Total length of body cm.
	Right ovary g.	Left ovary g.	Right cornu cm.	Left cornu cm.	
405	9·0	28·0	Slightly larger	2·15	175·3
406	13·0	20·0	P.par.	2·3	190·5
407	20·0	27·0	—	P.par.	193·0
409	16·0	14·5	2·2	2·3	177·8
412	19·5	27·0	2·6	P.par.	185·4
414	27·0	18·0	2·0	2·75	185·4
417	5·5	14·0	1·1	1·1	157·5
419	13·0	6·5	1·0	1·0	158·8
421	14·0	19·0	1·7	P.par.	172·7
422	10·0	18·5	1·5	1·5	175·3
423	13·0	7·0	1·1	1·1	152·4
424	15·5	22·0	1·8	P.par.	175·3
429	11·5	26·0	1·7	1·6	180·3
430	8·0	22·5	1·5	1·5	166·4
432	—	—	1·25	1·8	174·0
434	9·0	16·0	P.par.	1·5	170·2
442	15·0	9·0	1·2	1·3	160·0
445	15·0	11·0	0·9	1·0	160·0
446	—	—	1·1	1·1	162·6
450	5·0	4·5	1·0	1·0	154·9
457	11·0	9·0	1·1	1·2	157·5
458	3·5	2·5	1·7	1·7	143·7
465	5·0	7·0	1·0	0·5	160·0
466	12·0	6·5	1·0	0·9	160·0
468	6·0	6·5	1·0	1·1	167·6
470	14·0	14·0	1·5	1·8	170·2
475	—	—	2·6	Similar*	182·9
477	8·5	10·0	1·7	P.par.	160·0
478	31·0	28·0	1·8	1·8	193·0
480	15·5	20·5	2·9	2·7	182·9
482	11·0	8·5	1·6	1·7	157·5
483	20·0	16·0	2·5	2·3	185·4
489	15·0	9·0	1·4	1·4	182·9
490	3·0	10·0	0·85	1·0	142·2
491	13·0	15·0	P.par.	1·1	162·6
492	12·0	15·0	1·4	P.par.	170·2
493	9·0	14·0	1·1	1·1	160·0
497	22·0	14·0	2·0	2·0	182·9
499	15·0	23·0	1·8	2·6	182·9
501	12·0	18·0	2·1	Similar	190·5
502	16·0	14·0	2·0	Similar	190·5
504	13·0	15·5	1·8	1·6	185·4
507	9·0	7·0	—	1·0	167·6
512	5·5	6·0	1·4	Similar	139·7
514	39·0	16·5	Similar	1·7	190·5
515	7·5	15·0	1·7	—	175·3
517	11·5	14·0	—	—	195·6
518	9·0	8·5	1·2	1·8	162·6
519	18·0	21·0	2·0	1·9	180·3
520	—	—	1·8	P.par.	177·8
521	15·0	16·0	3·0	2·4	172·7
522	7·0	10·0	1·4	1·4	177·8
523	17·5	12·5	P.par.	2·4	167·6
525	17·0	12·0	P.par.	2·3	188·0
526	17·5	15·5	P.par.	1·8	193·0
527	22·0	25·0	2·7	2·6	185·4
529	17·0	9·5	1·8	P.par.	195·6
530	16·0	26·5	2·4	P.par.	168·9
531	32·0	24·0	P.par.	—	177·8
532	17·5	23·0	1·8	1·9	181·6

* "Similar" indicates that the cornu in question was about the same size as the other of the same animal, but that actual measurement was not possible owing to distortion or damage.

The heaviest individual testis was 57 g. (no. 449) and the lightest 36 g. (no. 469). The organs of a pair may differ by as much as 7 g. (no. 469), the weights being 36 and 42 g. There is no indication of seasonal variation in size or weight.

Histology

The results of microscopical examination of the male reproductive organs may be summarized as follows, the figures in brackets showing the number of specimens in each month represented.

March (2). No. 503. Spermatids few or absent and cellular debris in the seminiferous tubules, no sperms found. The nuclei of the large cells which occur are dark-staining and thus contrast with the "winter spermatogonia" described by Courrier in Chiroptera (Courrier, 1923, 1 and 2) which are pale although large: the otarian cells are more reminiscent of the "plasmodes spermatocytaires ou teratocytes seminaux" of van Beneden's manuscript to which Courrier refers (Courrier, 1927).

No sperms were found in the epididymis of no. 503. I consider this animal to have been exhausted by the exertions of the breeding season which had recently terminated.

No. 431. Spermatids are plentiful but sperms are very few; "teratocytes" occur. There are no sperms in the epididymis. Beginning of recovery from the sexual season.

June (2). Spermatids are present in both and a few sperms are being produced, "teratocytes" are present in no. 443 and doubtfully in no. 449. No. 443 has many sperms in the epididymis, no. 449 has none there but shows them in the vas deferens.

July (1). No. 464. (Pl. XXXI, fig. 1.) Even spermatocytes are becoming detached in this testis, "teratocytes" are present and there are a very few sperms in the epididymis. The testes were of a yellowish colour when fresh and the general appearance of the creature, which was in poor condition, suggested a lack of vitality but there was no sign of organic disease. The skull shows that this was an animal of somewhat advanced age but there is no definite evidence to show that the condition was one of senility.

August (2). Nos. 469, 500. These resemble one another, there is little spermatogenesis, "teratocytes" are present, and sperms were found in both epididymes but not in great quantity.

September (1). No. 471. (Pl. XXXI, fig. 2.) Spermatogenesis is proceeding actively and in almost every tubule of the testis, no "teratocytes" were seen and sperms are plentiful in the ducts.

October (1). No. 498. Spermatogenesis in progress, free sperms may be found in the seminiferous tubules and are abundant in the epididymis.

December (1, no. 479) and *January* (1, no. 415) are alike. The testes are in full activity and the epididymes contain a plentiful supply of sperms.

Comment. No. 503 was killed immediately after the breeding season, and it will be observed that no sperms were found; but in no. 431, which was killed only a fortnight later, sperms were present in the testis but not in the epididymis. In June, July and August sperms are to be found in the ducts as well as the glands, but in September there is initiated a marked increase in activity, which is very naturally continued into the breeding season. There is no clearly marked anoestrous period, but immediately after the breeding season there may be a time of more or less complete azoospermy, depending probably on the recent history of the individual. During the winter spermatogenesis is greatly reduced but not suspended, and on the approach of the breeding season (about September) this condition changes rather suddenly to one of full testicular activity. The winter aspect is associated with the occurrence of "teratocytes" in the testes.

The general behaviour of the animals is in keeping with the histological picture. After the breeding season the bulls spend a great deal of their time in sleep and are frequently seen in very poor condition indeed; as time passes their physical condition improves and by July bulls may often be seen to take an interest in cows. As the breeding season approaches, a state of rut becomes more and more obvious.

It is known that the size of the harem varies greatly and it is very probable that some bulls never acquire even one cow. In this event the breeding season would be the less exhausting, and there might well be produced a condition such as that of no. 431 in which there was a subsidence but not a complete cessation of spermatogenesis after the end of the breeding season.

OESTRUS, IN THE FEMALE

Ovary. It has been pointed out by Corner (1919) that the actual size of a follicle or of a corpus luteum has not a great significance. There must nevertheless be a minimum size related to sexual activity. Signs of oestrus are present in the uteri of nos. 465 and 457, where the largest follicles are only 0·7 and 0·69 cm. in diameter, and coitus was observed in no. 483 which had a follicle of 0·71 cm. The largest follicle is that of no. 521—2·29 cm.—and follicles between 1 and 2 cm. are common. After oestrus there is a marked reduction in size, the follicles ranging from 0·69 down to 0·27 cm. 0·7 cm. may, therefore, be considered as the minimum size for the active follicle.

Two newly ruptured follicles were found (nos. 412 and 527) in association with uterine epithelium of 30 and 35 μ; the ovarian capsules were filled with fluid and the follicles themselves were still in a collapsed state.

In the formation of the corpus luteum the granulosa cells, accompanied by a considerable number of leucocytes, advance from the circumference of the follicle from different points, and eventually the whole space is filled, there being no central cavity in the corpus luteum of this species. The fully formed corpus has the appearance of a number of roughly wedge-shaped masses converging on a more or less central point and separated by fibrous tissue derived from the theca externa, which carries the blood vessels into the substance of the corpus. When the space is filled the cells increase in size and become fully luteinized, producing finally a corpus luteum of normal structure.

Among the large cells may be found others, smaller and more darkly staining, which may correspond to the theca lutein cells of Corner (1919) which have also been termed paralutein cells (Gatenby, 1924): Corner considers that they are derived from the theca interna. After it has ceased to be functional the corpus becomes fibrous and regresses to what is sometimes called a corpus albicans, and it finally disappears altogether. It is highly probable that the degeneration may be slow, but it is not certain that it always proceeds at the same pace; in no. 436, which was killed in May, there was a well-developed corpus relating to the foetus of 10·2 cm., and in the other ovary there was an older corpus which showed the normal gross structure in a comparatively undegenerate state.

The corpora lutea in the post-ovulation ovaries range from 1·5 to 3·2 cm. in their longest diameter, about two-thirds of them being over 2 cm. Fully luteinized corpora are found in association with uterine epithelium of 30, 17 and 13 μ, and they vary from 2·2 to 2·3 cm. in diameter. In three seals, very recently post-partum, the corpora were 2·3, 1·8 and 0·59 cm.; all these animals were already in a state of oestrus. As many as three corpora may occur, although in most of the seals examined only one was present; in six there were two and in three, three, but at no time were signs of a greater number found. The temporary persistence of corpora lutea permits adequate explanation of the presence of more than one. For example, no. 421 was in a post-partum condition as well as early post-ovulation; therefore, of the two corpora in her ovaries, one was that of the late pregnancy and the other that of the later ovulation, and the condition of nos. 489, 491, 492 and 518 was comparable. No. 412 was at the height of oestrus, it had just ovulated and coitus was observed; there were two corpora lutea in one ovary (which is unusual) and the animal was in a recent post-partum condition. I conclude that of the two corpora, the smaller, of irregular shape, represented a sterile ovulation which had been succeeded by that to which pregnancy supervened, and that the older corpus had survived the whole of pregnancy in a recognizable state.

The animals in which three corpora can be identified, nos. 424, 504 and 519, all show signs of comparatively recent pregnancy and are in a post-ovulation stage; they do not really differ from no. 412 which has just been discussed. The oldest corpus is always very degenerate.

Uterus. (See Pls. XXXI and XXXII.) The resting epithelium is very low columnar or even cubical, about 8·7 μ in height. With the progress of oestrus there is an increase in height and 52 μ may be attained (no. 414). With the approach of oestrus there is fairly widespread degeneration of the cells, as is shown by vacuolization of the cytoplasm and pycnosis of nuclei; the vacuolization diminishes markedly in the later part of this phase. Pycnotic nuclei can almost always be found by search in the uterine epithelium, but they are far more plentiful in oestrus and particularly so in the earlier stages, which may be more correctly described as pro-oestrus. These nuclei are frequently, if not always, thrust out into the lumen of the uterus as regeneration takes place. Mitotic regeneration proceeds almost simultaneously with destruction, and at the end of oestrus the epithelium is high columnar with elongated nuclei situated about the middle of the cells. The post-ovulation condition is sharply marked by the disappearance of mitoses and vacuolization and a great reduction in the proportion of pycnotic nuclei. In post-oestrus the epithelium gradually subsides until it reaches the height of the resting stage.

The stroma passes from a compact condition to one of oedema during oestrus, becoming once more compact in the post-ovulation state. The uterine glands of the virgin are few and undeveloped, being little more than strings of cells. In the sections the amount of glandular tissue visible is relatively small during oestrus, the lumina are large and the amount of secretion small or there may be none. Mitoses are present in the epithelium, appearing there later than in the corresponding cells of the uterus. After ovulation the amount of glandular tissue visible increases greatly and it may occupy the greater part of the stroma; the lumina of the glands decrease in size owing to the growth of the epithelial cells from a more or less cubical to a columnar form, and secretion becomes plentiful. This condition declines towards the end of the post-ovulation phase but traces of it are sometimes found in the early part of oestrus, from which it may be concluded that one cycle may follow another fairly rapidly. It is not clear whether the increase of glandular tissue is due to proliferation of already existing glands or to an increase in their actual number.

As has been stated by Deansley and Parkes (1933) placental blood vessels may survive for a considerable time in an occluded form so that in section they appear as hyaline discs with few nuclei. In *Otaria* this condition has frequently been observed in seals of which it was known that they were post partum and also in others in which there was no gross appearance to suggest it.

In some of the uteri, particularly those of animals of the largest size, it was observed that there was what might be termed an accumulation of these vessels to such an extent that the stroma of both cornua was largely occupied by this tissue. The hyalinized blood vessels present impassable barriers to the growing glands and uteri which contain such vessels in large proportions are incapable of full glandular development. A similar phenomenon is observable in the post-partum cornua of seals which have ovulated after parturition and are in a state of pseudopregnancy or tubal pregnancy. It is difficult to avoid the conclusion that the uteri which display the hyalinized vessels in great abundance and are not recently post partum have passed the height of their breeding activity and are in this manner showing signs of senility due to the loss of those powers of recuperation which are necessarily correlated with continued sexual activity.

Oestrus may, and probably always does, occur almost immediately after parturition. Thus seal no. 531, which had given birth so recently that the uterus was still uncontracted, had the epithelium of the sterile cornu elevated to 17 μ and oestrous changes were in progress. I consider that this animal could not possibly have been more than twenty-four hours post partum.

Sperms were found in uteri with an epithelial height which varied from 20 (no. 477) to 53 μ (no. 414) and related to follicles from 0·71 cm. upwards. No. 477 has, therefore, been taken as marking the beginning of oestrus as differentiated from pro-oestrus, and an inspection of Table VIII will show that the transition from the follicular phase (oestrus) to the luteal (pregnancy or pseudopregnancy) is marked by the disappearance of mitoses from the uterine epithelium and the onset of great glandular activity: the height of the epithelium decreases steadily during the luteal period.

Coitus has already been described (1934), but it may be added that, judging by what was found in the uteri of newly served cows, the amount of semen emitted is surprisingly

Table VIII

Specimens illustrating the oestrous cycle

Reference no.	Ovaries		Uterus									
				Epithelium				Glands				
	Largest follicle cm.	Largest corpus luteum cm.	Condition of stroma	Height in micra	Mitoses	Pycnotic nuclei	Vacuolization of cytoplasm	Apparent numbers	Size of lumina	Amount of secretion	Mitoses	
450	0·45	a	c	8·7	a	p	a	Few and undeveloped				
515	0·95	1·79	c	8·7	1–2	p	a	m	l	pp	a	
465	0·70	1·50	c	8·7	p	p	p	n	m	p	a	
457	0·69	2·15	m	8·7–13	p	p	a	n	m	p	a	
514	1·47	3·00	c	13·0	p	p	p	f	l	p	a	
501	1·20	2·17	oe	10–17	p	pp	p	f	l	p	a	
531	0·69	2·31	oe	17	p	p	p	f	l	a	a	
477	0·90	1·80	oe	20	p	p	p	m	l	p	p	Sperms in uterus
525	0·77	1·80	oe	22	—	pp	p	f	l	a	—	Fixation poor
432	0·87	1·67	oe	22	p	p	a	n	m	m	a	
507	0·78	1·00	c	22	p	pp	p	f	s	a	p	
409	1·40	1·75	oe	22	pp	pp	p	n	l	a	p	
407	1·75	0·59	oe	22–30	p	p	p	f	l	a	p	
530	1·25	2·29	oe	24	p	p	p	f	l	a	p	Sperms in gland
512	0·95	a	oe	25	p	pp	p	m	l	a	p	Sperms in uterus, haematoma in ovary
480	1·00	Trace	m	25	p	p	p	f	l	a	p	Sperms in uterus
483	0·71	Trace	m	25	p	p	p	f	l	a	p	Coitus observed
448	1·35	1·43	oe	26	pp	p	p	f	l	p	p	
529	1·15	2·38	oe	26	p	p	p	f	l	p	p	Coitus observed
502	1·50	1·55	oe	26	pp	pp	p	m	m	p	pp	
405	2·15	1·93	oe	26	p	p	p	f	l	p	p	
406	0·98	2·58	oe	26–35	p	p	p	f	l	a	p	Coitus observed
522	0·82	1·90	oe	30	pp	p	p	m	m	p	p	
526	1·47	2·35	oe	30	p	pp	p	f	l	a	a	
532	1·0	2·10	oe	30–39	p	p	p	m	l	a	a	Sperms in uterus
527	—	Trace	oe	30	pp	p	p	f	m	a	p	Just ovulated
475	1·18	1·84	m	30–35	p	pp	p	m	l	a	pp	Sperms in uterus
521	2·29	1·87	oe	35	a	a	p	f	l	a	p	
482	0·83	1·20	oe	35	pp	f	p	n	l	a	p	Haematoma in ovary, sperms in uterus
412	—	1·90	oe	35	a	p	p	f	l	a	p	Coitus observed, just ovulated
458	0·92	None	oe	39	p	p	p	f	m	a	p	
414	1·28	3·00	m	52	a	p	p	f	l	a	p	Coitus observed
492	0·34	2·10	m	43	a	a	p	ab	s	m	a	Sperms in uterus
424	0·38	1·27	m	39	a	p	s	n	m	m	a	Sperms in glands
421	0·55	1·25	m	30	a	a	a	m	s	m	a	Sperms in uterus
518	—	1·65	c	30	a	a	a	m	s	p	a	Follicles small
422	0·42	3·22	c	30	a	f	a	n	m	p	a	
478	0·49	1·00	c	30	a	f	a	ab	s	pp	a	
489	0·54	2·13	c	26	a	f	a	ab	m	pp	a	
520	0·58	2·13	c	26	a	f	a	ab	s	p	a	
423	0·32	2·33	c	26	a	—	a	n	s	p	a	
429	0·64	2·82	c	26	a	f	f	m	m	pp	a	
493	0·32	2·45	m	22	a	a	a	ab	s	p	a	
504	0·46	1·70	m	22	a	f	a	n	m	pp	a	
430	0·42	3·22	c	17–26	a	a	a	ab	m	p	a	
491	0·40	1·45	c	17–22	a	a	a	ab	s	p	a	
468	0·65	1·35	c	17	a	p	a	m	s	p	a	
519	0·60	1·59	m	17	a	p	a	f	m	p	a	
417	0·40	2·38	c	17	a	f	a	ab	m	p	a	
419	0·36	2·20	c	17	a	a	a	ab	s	p	a	
466	0·48	2·17	m	17	a	f	p	n	m	p	a	
490	0·27	2·15	c	13	a	p	a	m	m	p	a	
445	0·52	2·38	c	13	a	f	a	f	s	p	a	
446	0·43	2·47	c	13	a	f	a	ab	s	p	a	
434	0·55	2·32	oe	13–17	a	p	a	ab	l	p	a	
470	0·58	2·50	m	8·7–17	a	p	a	ab	s	pp	a	
442	0·69	2·38	c	8·7–17	a	pp	a	ab	1	p	a	

Key to the abbreviations above. a = absent; ab = abundant; c = compact; f = few; l = large; m = medium; n = numerous; oe = oedematous; p = plentiful; pp = very plentiful; s = small.

small. It is almost clear and appears to be of a brownish colour. In no. 483 there was a little liquid even in a cornu. The os penis alone of no. 449, a bull of moderate size, was 18 cm. long so that the organ is quite capable of penetrating into the uterus: it was observed that the os uteri of no. 406 exhibited some dark patches as though it had been bruised.

There is no direct evidence as to whether ovulation is spontaneous or not, but since cows continue to ovulate—outside the breeding season—at a time when no copulation has been observed one must conclude that it is spontaneous. It is a matter for speculation whether the energy and enormous weight of the bull may not, *in coitu*, cause the expulsion of an ovum from a follicle which has already developed marked internal pressure: it has been remarked that the cows are visibly flattened during coitus.

Note. The left ovary of no. 480 was gorged with blood and one or two partly ripe follicles were filled with it: extravasated blood was also found in the ovaries of nos. 482 and 512.

Vagina. (See Pl. XXXII.) Vaginal material from 24 cows was preserved and from this it appears that the cycle is of the usual type in which growth, stratification, destruction and regeneration succeed one another. Neither cornification nor mucification occurs.

The epithelium of the anoestrous vagina is about 30 μ in height and is composed of two layers of almost cubical epithelium which are divided by a layer which stains less deeply than the rest of the cytoplasm; there is a distinct surface membrane (nos. 450, 477 and 465). With the onset of sexual activity proliferation takes place and the middle layers of the resulting compound epithelium become stratified, but the most superficial layers are thrown off (no. 409) and a highly developed condition of stratification is attained thereafter. This stage coincides with the earlier part of oestrus, as is shown by the presence of sperms in some of the corresponding uteri (nos. 482 and 475). The epithelium, which may have attained a height of 150 μ, is now invaded by large numbers of leucocytes, and the outer layers are sloughed off so that the epithelium is reduced to a thickness of three or four cells with a height of 30–35 μ and an irregular surface (nos. 477, 406 and 483; nos. 448 and 458 are also in the oestrous condition). This stage corresponds approximately with the end of oestrus, as is shown by the relevant uterine sections. During post-oestrus the vaginal epithelium again increases in height to a columnar form which has a thickness of 35–45 μ and a smooth surface (nos. 492, 489, 424, 470, 504, 491, 429, 417, 493 and 430). This columnar stage subsides to a condition closely resembling that described for anoestrus and having a height of 20–30 μ or even less (no. 422; nos. 434 and 466 are also in an advanced stage).

Table VIII is arranged to show, as far as possible, the changes from an anoestrous state through oestrus and post-ovulation to a condition which may be the beginning of a new cycle, resting, or the earliest stage of pregnancy, the last, of course, not being identifiable unless a blastocyst is found. No. 450, the first animal, is in a state of anoestrus, and having regard to the very small size of the ovaries and uterus, and to the entire absence of any trace of a corpus luteum in the former as well as to the small size of even the largest follicle, 0·45 cm., it is reasonable to conclude that this is a virgin.

The remainder of the specimens have been arranged first in ascending and then descending height of the uterine epithelium.

Table IX

Scheme of the sexual cycle in the female

Phase	Ovary	Uterus		Vaginal epithelium
		Epithelium and stroma	Glands	
Anoestrus	Follicles small	Low and inactive. 8·7μ high. Stroma compact	Few and inactive	Cuboidal. 30μ high
Proestrus	Follicles enlarge	Destruction and mitotic renewal with increase in height to 17μ. Stroma becomes oedematous	Unchanged	Proliferation and stratification, 150μ high
Oestrus, coitus	Ovulation	Activity continues, maximum height reaching up to 40μ. Stroma oedematous	Unchanged	Sloughing, 35μ high
Postoestrus	Formation and growth of corpus luteum	Well-developed columnar, but decreases steadily to anoestrus level. Mitoses absent	Enlarge and become very active but decreasingly so	Regenerates and subsides to 20–30μ

FOETUSES

With the exceptions mentioned the foetuses were measured in dorsal profile in the following manner. A very flexible wire was applied to the mid-dorsal line from the tip of the snout to the end of the tail, and when the wire was straightened out the length thus obtained was recorded as that of the foetus. The exceptions are the following, which were measured with the tape in the field: nos. 472, 508, 509 and 513. Further, the length of the twin foetuses of no. 510 is only approximate since, although I was close at hand and believed them to be sufficiently protected, these embryos were discovered and swallowed by gulls whose enterprise I had underestimated.

The smallest male pup measured was 80 cm. in length and the smallest female 76 cm.; the latter had a length of fresh umbilical cord still attached.

Note on pregnant uteri. In pregnancy the foetus and all its membranes are confined to one cornu, which is almost invariably that belonging to the ovary containing an active corpus luteum, but in seal no. 436 the corpus luteum of pregnancy was that in the ovary opposite the pregnant cornu and the corpus on the pregnant side was degenerate, it follows that the ovum must have passed from one cornu to the other. Fig. 6 is based on a field sketch of the uterus of no. 531 and shows clearly that pregnancy is entirely confined to one horn.

CHANGES IN THE STERILE CORNU OF THE PREGNANT UTERUS

In the earlier part of pregnancy the sterile cornu presents an appearance closely resembling that of the post-ovulation uterus, but about this time a regression begins which is completed by the time the foetus is a little over 50 cm. With considerable reservations the period may be estimated at four months, judging from the size of foetuses at successive periods (Table X).

Table X

List of foetuses in monthly succession

No. of female	Date	Length of female	Length of foetus	No. of foetus*
436	22. v	190·5	10·2	—
439	25. v	175·3	12·8	—
440	26. v	170·2	10·3	—
441	6. vi	163·8	15·6	—
1114	8. vi	190·4	10·7	1148
1129	8. vi	170·1	14·0	1130
1131	8. vi	177·7	13·3	1139
1132	8. vi	182·3	15·1	1121
1137	8 .vi	182·8	14·4	1140
1149	9. vi	180·3	13·1	1105
444	9. vi	162·6	23·0	—
1114	10. vi	190·4	15·6	1147
510	12. vi	170·2	16–17	—
508	25. vi	167·6	16·5	—
509	25. vi	146·1	20·3	—
513	9. vii	167·6	27·9	—
1030	29. vii	153·6	39·5	—
472	6. ix	171·5	53·3	—
511	10. ix	149·9	52·1	—

* Where no separate number is given the foetus bears that of the cow.

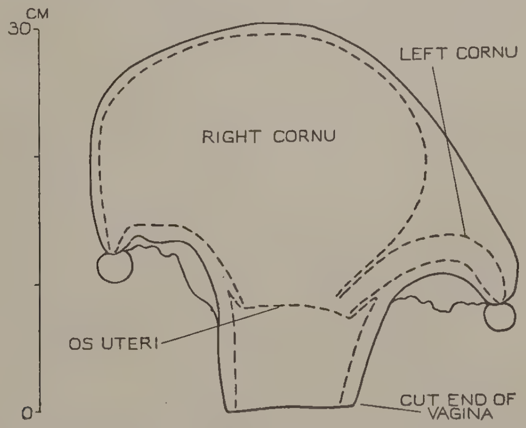

Fig. 6. Very recently *post partum* uterus of no. 531. From a field sketch.

In the sterile cornu of no. 436 when the foetus was 10·2 cm. the epithelium is of crowded columnar cells attaining a height of 39μ with nuclei in the middle of the cells. The glands are very numerous in section and secretion is plentiful. The blood vessels of the stroma are conspicuous for number and size. In the extra foetal part of the *pregnant* cornu of the same animal the epithelium is rather crowded and cubical and the glands are moderately numerous and much convoluted, but their epithelium is low and cubical: they are ceasing to function. The blood vessels of this cornu are small except at the base of the stroma, where they have a somewhat placental appearance.

The foetus of no. 440 is only 1 mm. longer (10·3 cm.) but the epithelium of the sterile cornu is subsiding, being low columnar, or even cubical in places. Glands are moderately plentiful, with cubical epithelium in the central and low columnar in the peripheral parts, and their secretion shows a marked diminution. Blood vessels are only moderately numerous. The extra-placental part of the pregnant cornu resembles that of no. 436.

TABLE XI

Measurements referring to the genitalia of pregnant females

Reference no.	Weight		Diameter	
	Right ovary	Left ovary	Right cornu	Left cornu
436	16·0	41·0	2·1 p*	1·6
439	36·0	14·0	1·6 p	1·1
440	17·0	11·5	1·2 p	1·2
441	8·5	14·0	1·1	1·1 p
444	6·5	18·0	1·4	— p
472	31·0	8·0	— p	1·0
508	27·0	14·0	— p	—
509	13·0	5·5	— p	—
510	32·0	11·5	— p	2·0
511	11·5	24·0	—	— p
513	20·0	7·5	— p	—

* The pregnant cornu is marked with a "p" and the measurement, when recorded, refers to the extra-foetal part. Material for the study of the non-pregnant cornu was secured from these animals.

No. 439, with a foetus of 12·8 cm., shows a slightly more advanced stage in the history of the sterile cornu. The epithelium is now cubical, and rather crowded, with a height of 11 μ and nuclei which occupy a considerable proportion of the cell as in the anoestrous uterus of no. 450. The glands, although fairly numerous in the section, are nearly exhausted, with most of their epithelium reduced to a cubical form. There is a considerable amount of secretion present. Blood vessels are numerous.

No. 441, foetus 15·6 cm. The condition closely resembles that of the last uterus but the glands, although moderately numerous, are farther advanced towards exhaustion. Much secretion is still present.

No. 510, twin foetuses of 16·5 cm. (approx.). Epithelium columnar but of moderate height—26 μ—not closely packed and cubical in places. Pycnotic nuclei are fairly frequent. Glands are fairly numerous but short, being restricted by the large number of blood vessels in the deeper regions of the stroma. The cells of the glands are low and there is a decrease in the amount of secretion compared with no. 439.

The foetus of no. 472 was 53·3 cm. in length. The epithelium of the sterile cornu is low columnar and pycnotic nuclei are plentiful. The glands are few and straight, being much reduced, although secretion may still be present. The blood vessels are small.

Summary of history of the sterile cornu

In the earlier part of pregnancy the epithelium declines from a fairly tall columnar to a cubical type but again rises to low columnar. The glands decrease in activity as pregnancy progresses, the central parts first becoming ductlike, a condition which spreads to the peripheral parts. Secretion is still in progress when the foetus is about 15 cm., but about this time the epithelium is much exhausted and the glands eventually decrease in size and complexity until with the 53 cm. foetus they are few in the section and straight, although even at this stage some secretion may be present. Blood vessels are large and numerous at a foetal length of 10 cm., but they also diminish so that when the foetus is 53 cm. they are few and small. The final condition, except for the slightly increased height of the epithelium, resembles that of the anoestrous uterus.

PUBERTY

The female becomes sexually active during the fourth year, not "about the end of the fourth year" as previously stated (1934, p. 297). In addition to the five fourth year cows of the 1930–2 series nine others were collected in 1933–7, and of them three had no corpora lutea in the ovaries, and whereas two (nos. 458, 512) had follicles over 0·9 cm. in diameter, the third (no. 450), which was the largest of the three, was in a quite inactive condition, not yet having begun ovulation.

Two of the nine (nos. 509, 511) were pregnant and the remaining four (nos. 417, 419, 423, 490) had ovulated, since each had a corpus luteum: no trace of previous corpora lutea was found in any of these four. It seems quite probable that the corpora lutea of these four cows were derived from first ovulations.

These nine cows were collected at different dates in January, February, June, July and September.

Having regard to the above it is my opinion that this animal begins to ovulate in its fourth year, sometimes so early as to permit of successful impregnation (nos. 509, 511), but perhaps more frequently in winter, or later. It should be assumed that the virgins are served for the first time at the age of four years.

SENILITY

The oldest age group consists of 18 seals of the tenth year or over and specimens from the genitalia of 14 have been preserved.

It is but reasonable to believe that this class extends beyond the tenth year, since two females of this species lived for 15½ (not 16½ as in Hamilton, 1934) and 17½ years in captivity and the latter was believed to be about two years old on arrival in London, but since that was in May she must have been about sixteen months or twenty-eight months old and must therefore have been almost nineteen or twenty years of age when she died.

Sections from five of the 13 uterine specimens exhibit in *both cornua* the hyalinized blood vessels which mark the sites of previous placentation. It is reasonable to conclude that such structures will be most persistent in animals whose powers of recuperation have been impaired by age, and the five are all animals of large size (nos. 478, 497, 499, 527 and 532). These structures have also been found in eighth and ninth year animals, one of each group.

No. 478 shows the most definite signs of failing activity. The uterus was hard and small, although the outside diameter of the cornua was 1·8 cm. The right ovary appeared at first sight to have no follicles, but search produced three which were very small and in the left ovary also a few small follicles were present. Each ovary contained the remains of a corpus luteum, one being more degenerate than the other, and in addition the left ovary had a small corpus luteum of 1 cm. diameter which shows few signs of luteinization, under the microscope.

DISCUSSION

After the breeding season the bulls which have taken part in it are exhausted and there begins a period of partial inactivity, much of it spent in sleep and lasting from the end of the breeding season, that is, the latter part of February, to July.

It is very probable that there is some sort of seasonal rhythm, since all bulls are quiet at this time, although glandular activity is not necessarily suspended, e.g. no. 431. The shedding of the old coat and its renewal take place at this time. Four months is a sufficiently long time for the rest and in July the bulls begin again to take an interest in the cows, as is shown by their efforts to keep females from escaping into the water when they try to go thither of their own accord or, sometimes, when they are alarmed, but this retentiveness is not marked with the fervour of the breeding season. The tendency to retain cows becomes more and more marked as winter gives place to spring and the rutting season approaches. By the end of August or the beginning of September bulls were noted as "very pugnacious" and as early as 13 September a bull was seen to make prolonged although unsuccessful efforts to cover a cow.

Further attempts have been observed in the first part of December and the first consummations were seen about the middle of the month (but see p. 153).

The earliest newly born pup was recorded on 16 November, but the middle of December must be regarded as the beginning of the pupping season. Production is slow at first but rapidly accelerates and attains its maximum in the first half of January. January 23 is the last definite date for a birth, but a pup with a piece of umbilical cord attached has been seen on the 27th, and a placenta has been found on the beach on the 28th, in spite of the abundance of carrion-eating birds which usually dispose of such debris as soon as it appears.

There is some indication that births may take place occasionally at times more or less remote from the recognizable pupping season. No. 1001 was killed in July and had been pregnant so recently that the uterus had not returned to the non-gravid condition, the outside diameter of the lately pregnant cornu being approximately 4 cm.; it is somewhat distorted.

One cannot be certain that this cow was delivered at full time, since there is always the possibility of abortion, and although it must be assumed that this is rare in wild animals, a marine mammal such as the sea lion is exposed to a possibility of violence from the sea from which land animals are immune. Three seals killed in September and two killed in November showed by the great size and the condition of the uterus that they had been pregnant recently, although no pups were seen in the neighbourhood of these cows. It scarcely seems reasonable to attribute all these, so near the breeding season, to abortion: traces of milk were found in one cow, no. 530, which strongly suggests that this animal had come to full time and, further, a newly ruptured follicle was found in a non-pregnant seal killed on 15 November, thus at least implying the possibility of a fertilization which might produce a birth prior to the regular pupping season.

The death rate is exceptionally high among the earliest pups. In three seasons 29 pups were seen on or before 16 December and of them 11 had died shortly after birth. It is my opinion that the five cows mentioned above had given birth in the normal way and had lost their pups. On p. 307 of my previous report comment was made on the frequency of deaths of pups born of isolated cows outside the rookeries. The factors suggested there will apply with still greater force to pups born before the breeding season has begun, since there is then no organization of rookeries and harems to which the cows can be attached, and in the period just before the breeding season the bulls are very ferocious and there is a tendency for the cows to be frightened away by the combats.

Coitus continues until the last days of January, having been observed on the 29th and 30th and even so late as 3 February. Sperms were seen in sections of the uteri of the following cows killed outside the period of observed coitus: nos. 477, 530, 512, 475, 492 and 424. The spermatozoa occur in the uterine glands in nos. 530, 492 and 424 but, as is well known, sperms can survive in a recognizable, although rather "fossilized", condition for long periods (Deanesley, 1935), so that these cannot be regarded as conclusive evidence that coitus has taken place even comparatively recently. In no. 512, 9 July, there are sperms actually in the lumen of the uterus and in an apparently fresh state, but they are most numerous in the openings of the glands. This seal therefore had been covered at a more relatively recent time than the three mentioned above. No. 475, killed on 16 September, and no. 477, 28 November, both had sperms in the lumen, the former many and the latter rather few: it is impossible to avoid the conclusion that both these seals had enjoyed coitus quite recently. No. 477 fits in with what is known of the breeding season in general, and the presence of sperms in a cow killed in September may be correlated with the occurrence of recent post-partum animals such as those which have been discussed above. No. 512 is in a different category; this animal was collected at a time which is known to be about six months distant from the height of the breeding season and the finding of sperms in the lumen of a uterus is an indication of tolerably recent copulation. It has already been stated that from July onwards bulls have been seen paying attention to cows, and from this it is reasonable to conclude that there is occasional coitus, but it should be assumed that it is infertile unless indeed no. 1001 was delivered of a full-time pup. It is certain that if pups are born in winter they are extremely rare; I have never seen one in the course of four winters' work; and there is no reason to assume that coitus is necessarily fruitful in the lower animals. For example, there is every reason to believe that the stoat copulates during about eight and a half months of the year, whereas the females can become pregnant during only six weeks of the period although they ovulate at other times (Deanesley, 1935), so that sterile intercourse must be frequent.

In dealing with a wild animal such as *Otaria* it is obviously impossible to ascertain the length of the oestrous cycle by anything approaching the methods used with laboratory animals, so that all that can be hoped for is that an estimate of some sort may be arrived at by indirect methods. Of my series 19 were killed in the first three months of the year. The two earliest were both in a very advanced state of oestrus, one of 9 January had just ovulated and coitus was observed, the other, of 13 January, contained a very large follicle and had the highest uterine epithelium observed (52μ) and coitus was seen. In the second half of January, in February and in March 17 seals were killed and they were all in a state of post-ovulation activity, pseudopregnancy or very early pregnancy, which are indistinguishable states, unless blastocysts are found. From June to September the seals killed include both oestrous and post-ovulation animals, although the former are in the majority. But this may have been due to the relative ease with which non-pregnant animals are picked out if they are attended by bulls, who would naturally be more attached to oestrous than to post-ovulation cows. In December, that is, in the earlier part of the breeding season proper, eleven cows were killed, all in oestrus. It may be tentatively suggested that although cows come on heat very rapidly indeed after parturition (e.g. no. 531, p. 145), the succeeding stages of pseudopregnancy, when fertilization has not taken place, extend over some weeks, and this does not seem unreasonable when the length of pregnancy is considered (1934, p. 300). That the species is polyoestrous is shown by the overlapping of the last stages of the post-ovulation condition with the earlier stages of oestrus, e.g. nos. 465 and 457, which display mitoses etc. in the uterine epithelium as well as some glandular activity.

I have killed specimens in oestrus or post-ovulation stages in every month except April and May. There are no animals from April and those of May are unfortunately all pregnant. The two October cows were very large animals with massive uteri which contained many hyalinized blood vessels; their follicles were all less than 0·7 cm. in diameter, but each had a well-developed corpus luteum. There were no mitoses in the uterine epithelium and the glands were rather active. I consider that these animals are in a pseudopregnant condition which is masked by the signs of senility indicated above.

It appears then that in spite of the occurrence of a quite well-defined breeding season there is no division of the year into oestrous and anoestrous periods. On the contrary, *Otaria*, as a species, is sexually active all the year round.

Since neither sex has periods of functional sterility the reason for the contraction of the breeding periods into a comparatively short time in summer is obscure. The necessity of suckling a pup cannot be a controlling factor, since both lactating and non-lactating cows are present in the collection of sexually active animals. It has been suggested that one factor may be the increased intensity of the light in summer, and in connexion with this it would be of the greatest interest to know the habits of *Otaria byronia* in Galapagos, which is almost on the Equator.

The significance of the "teratocytes" in the testes is unknown, but they occur only in the season when there is no breeding, except perhaps in the rarest cases (p. 142).

CENSUS OF THE HERD IN THE FALKLAND ISLANDS

THE COUNT OF PUPS

It is perhaps hardly necessary to state that the most accurate basis for an estimate of the population is a count of pups, since they are the only class of seal of which the whole is ashore at one time. I find that such counts can be carried out during a period longer than that indicated on p. 309 of my previous report: they are satisfactory if made between the end of pupping, say 21 January, and the end of February, a period when the harems have broken up and the pups are collected in groups, more correctly "pods", which may contain any number from a mere handful of animals to hundreds.

It must be taken as a general rule that pups cannot be counted at high water. Some scope of beach is necessary for handling them. If the animals are confined to the beach matters are easier than when they have gone up into the tussac grass which is the usual background; and the seal are very fond of doing so. The principal difficulties lie in the agility of the pups and the sometimes alarming obduracy of adults, especially the more aggressive males.

The method depends on getting rid of the older seals without allowing the pups to escape, and this is possible only on account of the lower speed of the latter. When the seals are only on the beach the separation can be achieved by approaching them from the water briskly and rather noisily so as to produce a general stampede, which is always directed towards the sea; the pups get left behind and are cut off and driven up the beach. A watch should be kept for any that escape and their number noted. When the pups have been collected in this manner they are allowed to escape so that they can be counted as they go, that is, either in a thin steady stream or in small groups. Numbers are written down whenever there is a cessation of counting for any reason at all, even if there is but one to record. Full use should be made of natural features such as large boulders, clay banks, walls of rock and so on which will serve to contain the pups.

Seals in the tussac must be driven out on to the beach and there separated, but the ground must be searched after the general rush, since some animals manage to sleep through the uproar and it is a disadvantage to have even pups rushing down suddenly, and something more than a disadvantage if a large and alarmed bull suddenly appears.

There is a great variation in the ease with which different rookeries can be counted. Those which show a considerable length of flat beach are the best; some can be counted by only two men but four is a far better and more efficient number.

A certain delicacy has to be observed in dealing with crowded pups, since too close an approach may result in their breaking, and they have always an inclination to try to escape. The bite of the pup, although annoying, is not serious.

It should be added that, owing to their exposed nature, the majority of the rookeries can only be worked in favourable weather.

In the course of three seasons, 1934, 1935 and 1936, sixty-four rookeries were visited, of these fifty-six were counted. The remaining eight were estimated after inspection and were all small rookeries (Pl. XXXIII).

In the following table the rookeries have been divided into six more or less natural groups which have been numbered with Roman figures. The rookeries are themselves numbered consecutively and after each is the number of pups counted.

TABLE XII

	Position	No.	Date
I.	1. Jason West Cay	500e	10. ii. 35
	2. Jason East Cay	250e	10. ii. 35
	3. Grand Jason Islet	414	9. ii. 35
	4. North Friday Island	1814	8. ii. 35
	5. South Friday Island	750e	8. ii. 35
	6. Flat Jason Island	6041	9. ii. 35
	7. Elephant Jason Island	684	10. ii. 35
	8. South Jason Island	17	10. ii. 35
	9. West North Fur Island	465	8. ii. 35
	10. North Fur Island	7693	8. ii. 35
	11. Sedge Island	2782	2. ii. 35
	12. Wreck Island	1941	2. ii. 35
	13. South Fur Island	5010	4. ii. 35
	14. West Twin Island	1495	4. ii. 35
	15. Carcass Reef	226	1. ii. 35
	16. Low Island	3316	6. ii. 35
	17. Dunbar Island	768	6. ii. 35
	18. West Port Egmont Cay	1163	28. ii. 34
	19. East Port Egmont Cay	696	28. ii. 34
	20. Pebble West Islet	302	28. ii. 34
	21. Pebble Islet	272	28. ii. 34
	22. White Island	108	28. ii. 34
	23. North West Passage Island	161	28. ii. 34
		36,868	

	Position	No.	Date
II.	24. Split Island	3325	12. ii. 35
	25. Cliff Island	400e	1. ii. 35
	26. Fourth Passage Island	5779	29. i. 35
	27. Third Passage Island	7777	30. i. 35
	28. Second Passage Island	200e	31. i. 35
		17,481	
III.	29. North Island	4	29. i. 35
	30. Saddle Island	4	31. i. 34
	31. New Island	19	1. ii. 34
	32. New Island Seal Rocks	35	29. i. 35
	33. Channel Islands	75e	30. i. 34
	34. Clump Island	720	28. i. 34
	35. Pitt Island	4087	28. i. 34
	36. Quaker Island	248	26. i. 34
	37. Quaking Pass, Weddell Island	2061	27. i. 34

TABLE XII (*contd.*)

III.	38.	Unnamed, off Weddell Island	951		27. i. 34
	39.	Bald Island	130		3. ii. 34
	40.	Outer Island	1938		4. ii. 34
	41.	Circum Island	1247		24. i. 34
	42.	Stop Island	12		6. ii. 34
	43.	Tussac Island, South Harbour	1217		24. i. 34
			12,748		
IV.	44.	Cape Meredith	85		15. i. 32
	45.	Arch Island	2		13. ii. 34
	46.	North Arch Island	19		13. ii. 34
	47.	Cussack's Island	246		14. ii. 34
			352		
V.	48.	Barren Island	12		9. ii. 31
	49.	George Passage Islet	37		17. ii. 36
	50.	Blind Island	274		12. ii. 36
	51.	South-east Elephant Cay	200e		17. ii. 36
	52.	South Elephant Cay	150e		17. ii. 36
	53.	West Elephant Cay	150e		17. ii. 36
	54.	North (Main) Elephant Cay	2569		17. ii. 36
	55.	Calista Island	2073		18. ii. 36
	56.	North Wedge Island	201		18. ii. 36
	57.	West Island	77		18. ii. 36
	58.	West Tyssen Island	647		14. ii. 36
	59.	Sandy Island	291		14. ii. 36
	60.	Tyssen Islet	1494		14. ii. 36
	61.	Outer North West Island	838		19. ii. 36
			9013		
VI.	62.	Tamar Pass Islet	350		4. i. 32
	63.	Cape Dolphin	3393		14. ii. 37
	64.	Macbride's Head	350		27. xii. 30
			4093		
				80,555	

The presence of the letter "e" after a number signifies that it is estimated.
Nos. 65 to 68 are unimportant rookeries in which the numbers were not estimated.

ESTIMATES OF THE TOTAL HERD

The season of the count of the last section, 1937, has been chosen for estimates of the entire herd, and two are presented. A, with the assumption that the herd has already attained its maximum size and is now in a state of equilibrium, and B, with the assumption that the numbers are increasing.

In arriving at the final figures account has been taken only of the dead pups actually found. They amounted to 0·56 per cent of the total, but I have little doubt that the number was too low. Pups are fragile creatures and when dead might easily be destroyed, and it was hardly ever possible to search the ground so closely as to ensure that all dead pups had been found. In one small rookery 5·6 per cent dead pups were counted, but since the total there was less than 300 I have refrained from applying to the whole herd a correction of this magnitude which would entail an addition of 4511 to the count. Moreover, it is quite possible that the infantile death rate varies from one rookery to another, as it does with the Northern Fur Seal (0·8 to 2·8 per cent).

It has been quite impossible to form any estimate of the number of the mature but non-breeding cows which exist in small numbers, and although meticulous accuracy may suggest that some correction is desirable for these as well as the dead pups, from the practical point of view of the management of the herd it is satisfactory to realize that in these matters the figures of the estimates err on the side of conservatism.

The factors which have to be taken into account in forming estimates of the population are these:

1. The count of pups.
2. The length of life.
3. Rate of increase.
4. Deaths from all causes.

The number of pups is known to be approximately 80,555 and the length of life has been discussed before (1934, p. 306), when twelve years was suggested as being a reasonable length of life for males and eleven for females. Having regard, however, to the exceedingly strenuous life of the bulls as compared with the cows, after renewed consideration I now suggest that the latter, on average, may well attain the age of twelve years, and therefore the period during which their numbers may be directly inferred from the count of pups is seven years, although in fact the cows would be sexually active for eight years, that is, from the age of four (p. 151). Since, then, males are adult at the age of six years and cows pup for the first time at the age of five, it follows that the males have an actual sexual life of six, and the females of seven years, and the sexes will naturally be represented in the proportion of six bulls to seven cows in the herd in its natural state. One-sixth of the bulls and one-seventh of the cows will die annually, 16·66 and 14·29 per cent respectively, and accessions of these proportions will be necessary in order to maintain the herd in a state of equilibrium. From these figures and the number of the pups the total deaths between birth and maturity can easily be calculated.

The sexes are born in equal numbers, so that with a pup count of 80,555 there would be 40,277·5 of each, but since one cannot properly consider 0·5 of a living animal I have adopted 40,277 as the basal number.

The number of immature animals is calculated by taking the number which must die between birth and maturity, and making annual deductions of such dimensions that the final figure satisfies the demands of the herd for its annual accessions. The death rate will be heaviest in the first year (1934, p. 309), and I have therefore allotted to it a death rate of 40 per cent. The remaining deaths which have to be accounted for are distributed in the following manner, since it is but reasonable to expect that the annual rate will decrease as the animals become more mature. A and B refer to the alternative estimates mentioned above.

It will be observed that B assumes lower death rates than does A.

Estimate A. Count of pups 80,555 and, from that, parous cows, by inference, 80,555. Since the bulls are present in a proportion of six to seven cows there will be 69,047 bulls if there has been no artificial death rate, but in the Falklands a commercial sealing company has been operating rather irregularly since 1928 and it has killed in six seasons a maximum of 32,183.

TABLE XIII

Immature death rates per cent

	Males		Females	
	A	B	A	B
2nd year	20	15	20	20
3rd year	15	10	17	15
4th year	15	8	16	12·5
5th year	10	8	14·6	11·6
6th year	8·5	7·2	Parous	

Since the herd is assumed to be in a state of equilibrium the stock of bulls before killing was 69,047 and the annual accessions, 16·66 per cent (p. 158), number 11,508. The numbers of the annual killing are known from returns except for 1936, so that the maximum figure under the licence, 10,000, has been used. As shown in Table XIV by making the appropriate additions and subtractions the number of bulls in 1937 is estimated to be 50,895.

Table XIV

Stock of bulls

Year	Stock	Killed	Residue 1	Deaths of residue 1 = 16·66%	Residue 2	Accession = 16·66% of 69,047
1928	69,047	3,139	65,908	10,980	54,928	11,503
1929	66,431	2,065	64,366	10,723	53,643	”
1930	65,146	4,941	60,205	10,030	50,175	”
1931	61,678	2,819	58,859	9,806	49,053	”
1932	60,556	—	60,556	10,089	50,467	”
1933	61,970	—	61,970	10,324	51,646	”
1934	63,149	—	63,149	10,521	52,628	”
1935	64,131	9,219	54,912	9,148	45,764	”
1936	57,267	10,000	47,267	7,875	39,392	”
1937	50,895	—	—	—	—	—

Immature seal. The 11,508 males needed to maintain the untouched herd of 1937 will have been derived from the male pups of 1931, namely, 40,277, with deaths amounting to 28,774 or 71·44 per cent of the pups born. Of these 11,510 are assumed to have died in their first year, and the remaining 17,264 to have died at the rates set out in Table XIII. Since the supply of pups under the present estimate is constant, the number of immature seal of any age is easily found. The immature males under estimate A amount to 86,471.

The 80,555 cows require, to maintain their numbers, an annual accession of one-seventh, that is 11,511, which, being derived from 40,277 female pups, entails the deaths of 28,766 immature females, namely 71·42 per cent. The deaths in the first year will be

40 per cent (11,506) and in each of the remaining four years at the rates shown in Table XIII. The total number of immature females computed in this manner is 73,024, which includes 13,479 virgin four-year-old animals.

Under estimate A the total herd is composed as follows:

Pups, count	80,555
Cows, by inference	80,555
Bulls, table	50,895
Immature males	86,471
Immature females	73,024
Total	371,500

Estimate B. Certain views expressed previously (1934, pp. 310, 314 and 315) require modification or alteration. After somewhat lengthy calculations based on the assumption that the annual rate of increase is 8 per cent it was found that this entailed so large an accession of newly adult seal that it seemed extremely unlikely that the death rate of immatures could be so low as to permit it. This death rate, for males, amounted to only 38 per cent of the pups, during the whole of their immature life.

From what is known, not only of *Otaria byronia* but also of *O.* (*Eumetopias*) *jubata*, *Zalophus californianus* and *Calorhinus alascanus*, it is certain that the death rates of immature seal are very heavy, and it would be unreasonable to suppose that *O. byronia* departs from the normal state of affairs in the Otariidae (see 1934, p. 309.)

Additional calculations led to the opinion that a revised estimate of the annual increase at the rate of 2 per cent was in closer accord with the probabilities than the earlier figure of 8 per cent, and 2 per cent has therefore been adopted for the estimate, based on the assumption that the herd is increasing. This permits a death rate of adequate size and also averts the necessity of assuming that the number of breeding cows has increased from something over 49,000 to just under 98,000 in the nine years 1928–37, an enlargement which could scarcely avoid advertising its presence.

If, then, the herd is increasing at 2 per cent per annum and, as it obviously must, is maintaining the proportions of the different classes, it is easy to calculate the numbers at any time removed from the present. The method of computing the numbers is similar to that which has already been used for estimate A. The loss of one-sixth of the bulls and one-seventh of the cows must be replaced annually, but in this case there must be further accessions large enough to provide an increase of 2 per cent, so that the accessions must number 18·66 and 16·29 per cent for males and females respectively. The deaths of seals before reaching maturity under this estimate are 63·98 per cent for males, and 64·04 for females.

Since the census was not confined to one season a correction of 2 per cent per annum has been applied to counts made previous to 1937, with the result that for that year the number of pups appears as 83,879, and by inference the number of parous cows is the same. This number has been made the basis for the other calculations necessary.

By the use of the same method as for estimate A the number of bulls has been computed, with reference to the 2 per cent annual increase, at 53,277 in January 1937; male immatures number 94,488 and female 73,977.

Under estimate B the herd accordingly numbers (1937):

Pups, count, adjusted	83,879
Cows, by inference	83,879
Bulls, by calculation	53,277
Immature males	94,488
Immature females	73,977
Total	389,500

The total is about 5 per cent larger than that of estimate A.

FUTURE PROSPECTS OF THE HERD UNDER COMMERCIAL UTILIZATION

From the economic point of view the herd is of interest solely as a source of oil-production, and its value as such depends entirely on the number of bulls in excess of those required for breeding.

Bulls are required in the ratio of one to each 7·5 cows (1934, p. 315).

Estimate A. The 80,555 cows required 10,741 bulls, and the bulls in turn require 16·66 per cent annually to maintain their numbers against natural deaths, that is 1789. The annual accession of bulls is 11,503, which gives an annual surplus of 9714 bulls, a constant figure so long as the herd retains its present size.

Estimate B (1937). 83,879 cows will require 11,184 bulls, and these entail an accession of 18·66 per cent, that is 2087.

The number of bulls becoming adult is 13,416, which would provide a surplus in that year of 11,329 or 13·51 per cent of the counted cows. According to computations regarding the five subsequent years the surplus increases at the approximate rate of 2 per cent. So far the accumulated bulls have been ignored.

Virgin cows. In addition to the cows which have pupped there would be annually a large number of virgins coming up annually for service. Under A this is the constant number of 13,479 and under B it is 16·5 per cent of the cows which have pupped, in 1937, i.e. 13,832. The total number of cows requiring service is therefore A, 94,034 or B, 97,711. If the supply of bulls were reduced to the calculated number required for service, at the rate of one bull to 7·5 of the parous cows, the actual number of cows for service by a bull would be 8·17 (A) or 8·74 (B). Both of these numbers are below the figure which has been proposed as a suitable basis for management of the herd, that is nine cows per bull (1934, p. 303).

It has been so far assumed that the stock of bulls has been reduced to the number calculated as being required for service. If this were not done, but an annual killing of 10,000 made, the effect on the herd would be that, under estimate A, the stock of bulls would gradually diminish for over fifty years and would then arrive at a state of equilibrium when there would be 19,024 bulls before and 9024 after killing, with a constant annual accession of 11,503, which would naturally take place at the breeding season when the young bulls become six years old. All the bulls would obviously have opportunity of service before the killing. It follows that there should be an ample supply of bulls for breeding purposes since 19,024 bulls would entail only 4·94 cows each.

Under estimate B the number of bulls reaching maturity in 1937 would be sufficient to serve the total of 97,711 cows at the rate of 7·28 cows per bull, and if the killing were so great (42,000) as to leave only such a number as should be reserved for the cows of the year, the accession at the beginning of 1938 would raise the total to 23,005, which would be in the ratio of one bull to every 4·33 cows of the 99,665 available in that season. But the extent to which newly adult bulls should take part in breeding is questionable.

Calculations have been made on the basis of a killing of 15,000 annually from 1937 onwards, and they result in a minimum figure of 6649 bulls as the residue after killing (in 1947). These should receive an accession of 16,518, making a total of 23,167 bulls for the breeding season of 1948. The 23,167 bulls would be expected to serve 104,293 cows, and 17,208 virgins making a total of 121,501, an average of 5·24 cows per bull. After 1947 the residue increases.

It is my opinion that with the herd already in a state of equilibrium an annual killing of 10,000 could be contemplated with equanimity, and that if the rate of increase is only 2 per cent a somewhat larger killing should not be injurious.

It must, however, be emphasized that these are *estimates* and that the management of a herd of seals is inevitably empirical. Constant attention is required and it should be remembered that changes may be found to be necessary in fundamental figures such as those for length of life, optimum proportion of bulls to cows, or death rates. In the management of the Pribilof Islands fur seal assumed death rates have had to be altered from time to time in order that the estimates should fit the observed facts.

Since they might well have been written with reference to the herd of sea lions in the Falklands I cannot do better than conclude with the following quotation from the "Report on the Fur Seal of the Pribilof Islands" (Osgood, 1916).

> The nature of sealing as a business is such that restrictions of a fixed and absolute character are highly impractical. Living animals subject to the ravages of disease, to the inroads of natural enemies, to the vicissitudes of an (unusually) stressful existence and to the varying results of peculiar breeding habits cannot be successfully managed under inflexible rules laid down in advance.
>
> The establishment of close season for game animals is quite a different matter from the restriction of killing of fur seals.
>
> Among wild animals the fur seal is unique in many respects. Although not actually under domestication it is by nature and habits almost strictly comparable to a domestic animal and the principles governing its management should unquestionably be those employed by breeders of stock. Rigid rules of procedure, therefore, are as inadvisable in the case of seals as they would be with horses, cattle or sheep. So far as possible regulations should be sufficiently elastic to take advantage of conditions as they arise. The number of males which should be killed or reserved cannot, in the nature of the case, be absolute.
>
> Whether the herd be large or small, diminishing or progressing, good management demands... that action may be governed by circumstances.
>
> Inflexible rules applied to living animals are dangerous under any circumstances....
>
> The relative proportions of males and females should be the same in a herd of a thousand seals as in one of a hundred thousand or a million, and in any case it is wholly a matter of proportion not of fixed numbers.

NOTES

ON MIGRATION

After the breeding season the herd at Cape Dolphin gradually becomes smaller, and it continues to diminish as the winter progresses. A count in August gave a figure of 2545, including 183 bulls. With the approach of the breeding season the seals reappear, the bulls selecting sites on the beaches and being there joined by the cows. This repopulation takes the form of a gradual filling up from the north end of the rookery.

By the middle of January the herd is reconstituted. A count on 20 January showed 5854 seals, including 723 bulls.

At nearly all times there is a considerable amount of coming and going between the land and the sea and it is therefore inevitable that there should be some variation in the composition of the herd. It is nevertheless quite clear from constant inspection that the great diminution in counted numbers represents a real reduction of the herd and that the minimum is to be found in the middle of winter.

There is undoubtedly some local movement. It has been observed to a limited degree, but I consider that there must also be a genuine partial migration, at least in the sense that the seals leave the islands, although it may be that they go no farther than certain feeding grounds which are known to exist and where one expects to see not only seals but birds and whales, most usually *Balaena physalus*, an area such as that about 120 miles N2° W from Cape Pembroke.

I have observed on more than one occasion the occurrence of a quite unusual and conspicuous congregation of seals on the extreme northern end of Cape Dolphin. On 12 December there were 1084 adult or almost adult males and 186 cows at this place, where there had been only 243 males but about 500 cows on 5 December. The importance of such concentration lies in the fact that the population normally contains nothing approaching such numbers of bulls and cows. Of the latter there were 105 with 27 pups on 21 January, 67 with 13 pups on 3 February and on 4 February (of the previous year) there were 45 cows and 23 pups, these numbers representing the ordinary state of affairs at this site. Further, on 13 December of one year I saw a herd of perhaps 500 seals some distance off shore to the north; they were gradually drawing in to the land and presently began to come ashore. The unusual features of this phenomenon were that the herd was all moving steadily in the same direction and that there was no reason to believe that they were feeding, since no sea birds were attracted to the same area of water, as would have been the case if there had been feed there.

Having regard to the behaviour of the seals, the absence of signs of feed and the time of the year I am compelled to adopt the view that this was a party returning from migration.

In this connexion it is interesting to recall Devincenzi's statement that from Lobos Island there is in early winter a migration to the *South*. Such a movement would be in the direction of other known feeding grounds. It seems possible that a large part of the *Otaria* herd of the Falklands may put to sea in winter as the whole herd of *Calorhinus* does in the Pacific.

ON A NEW PARASITE

Specimens of a parasite belonging to the Siphunculata were collected from one or two pups found dead. Through the kindness of Miss Theresa Clay of the British Museum I am able to state that they belong to the genus *Antarctophirus* and resemble the species *microchir*, but it is considered by Miss Clay that in the absence of material from the type host, *Phocarctos hookeri*, my specimens should not be definitely allotted to the species named.

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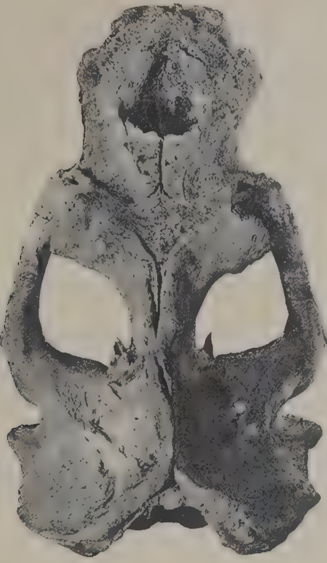
PLATE XXVI

Exceptionally large male skull, with ordinary male skull for comparison

Figs. 1, 2, 3. Dorsal, ventral and lateral views of large skull (No. 393).

Figs. 4, 5, 6. The same views of an ordinary skull (No. W.S. 479).



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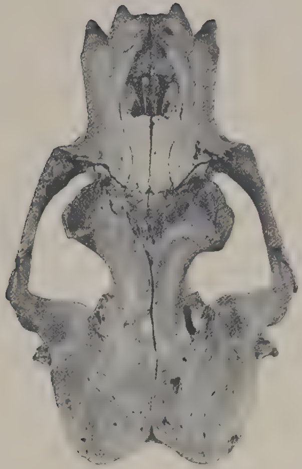

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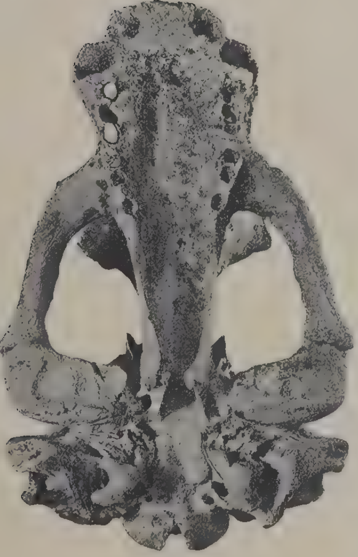

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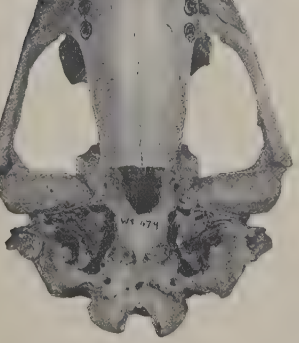

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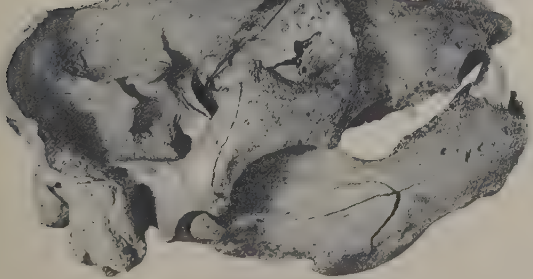

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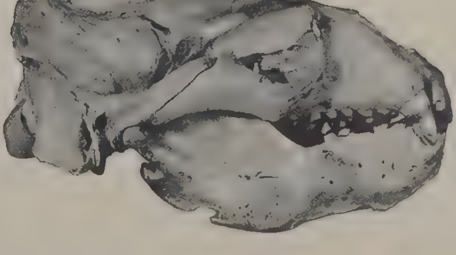

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PLATE XXVII

Female skulls in dorsal view, to show developmental stages

Fig. 1. Fourth year group, No. 509.

Fig. 2. Fifth year group, No. 465.

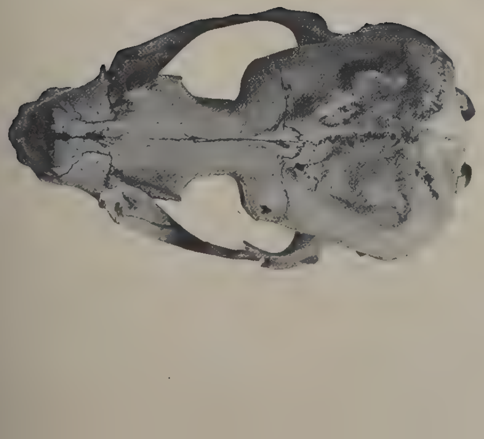
Fig. 3. Sixth year group, No. 515.

Fig. 4. Seventh year group, No. 522.

Fig. 5. Eighth year group, No. 475.

Fig. 6. Ninth year group, No. 529.

Fig. 7. Group of tenth year and over, No. 525.



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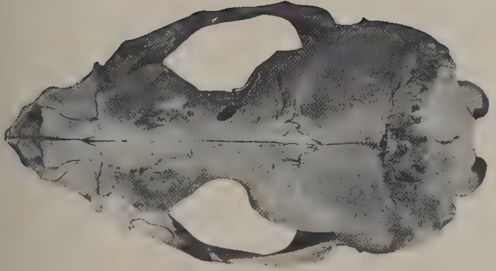

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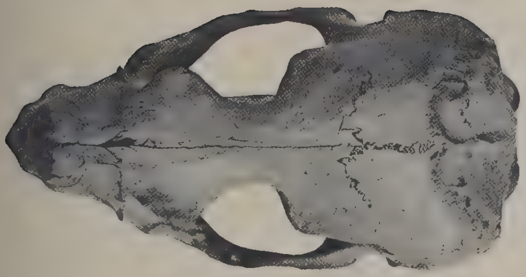

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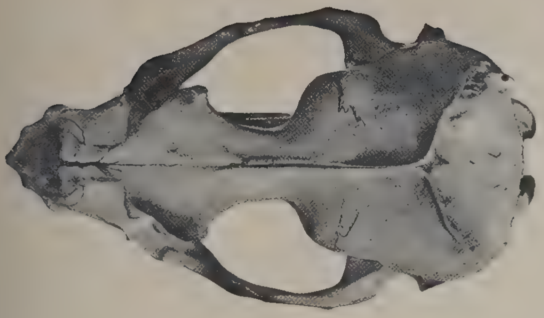

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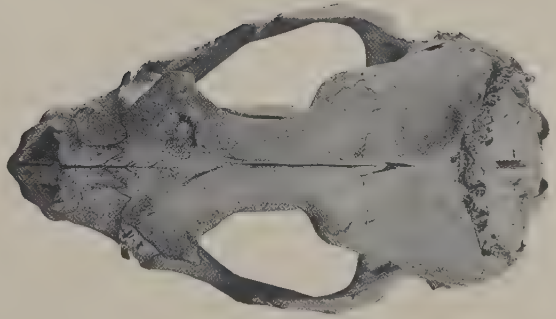

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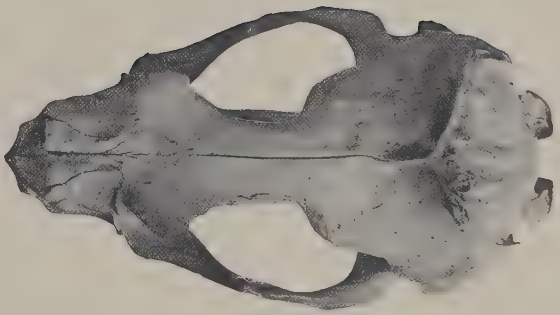

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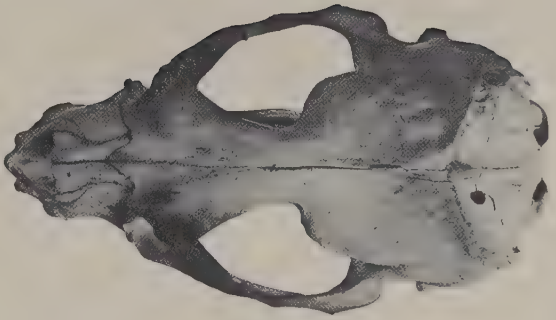

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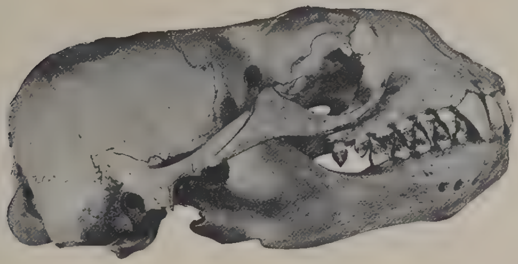
PLATE XXIX

Female skulls in lateral view, to show developmental stages

Fig. references as for Pl. XXVII.



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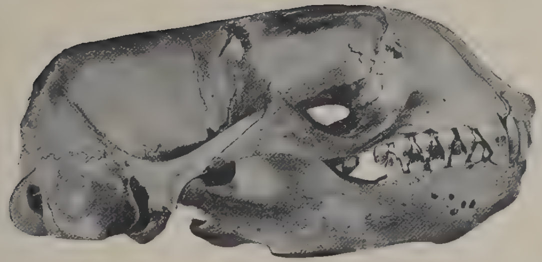

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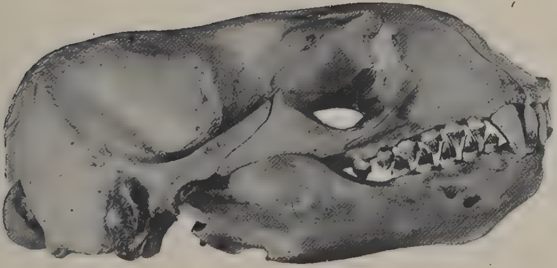

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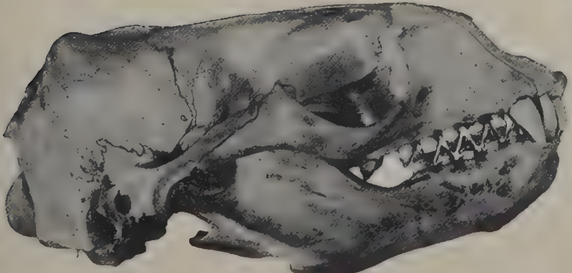

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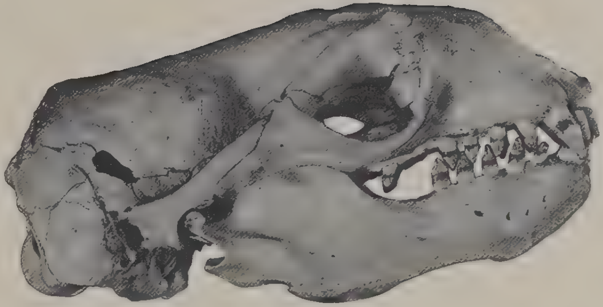

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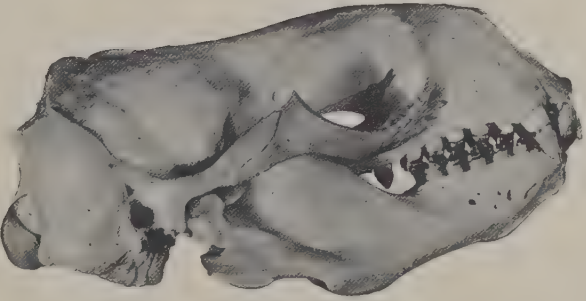

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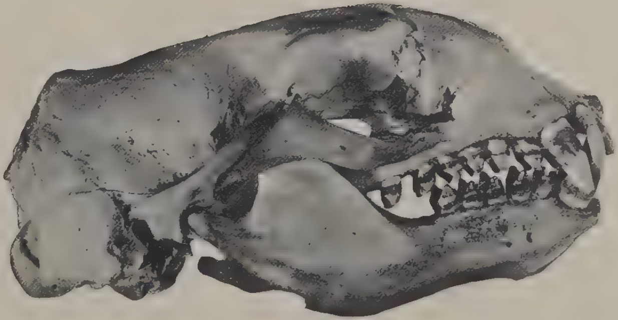

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PLATE XXX

Genitalia of ♀ No. 475, opened from the dorsal side

The left cornu is intact and the capsule, which had to be opened in the field, has been arranged over the left ovary as nearly as possible in the position occupied in life. The capsule of the right ovary has been reflected and the dorsal half of the ovary removed. An old corpus luteum is visible.

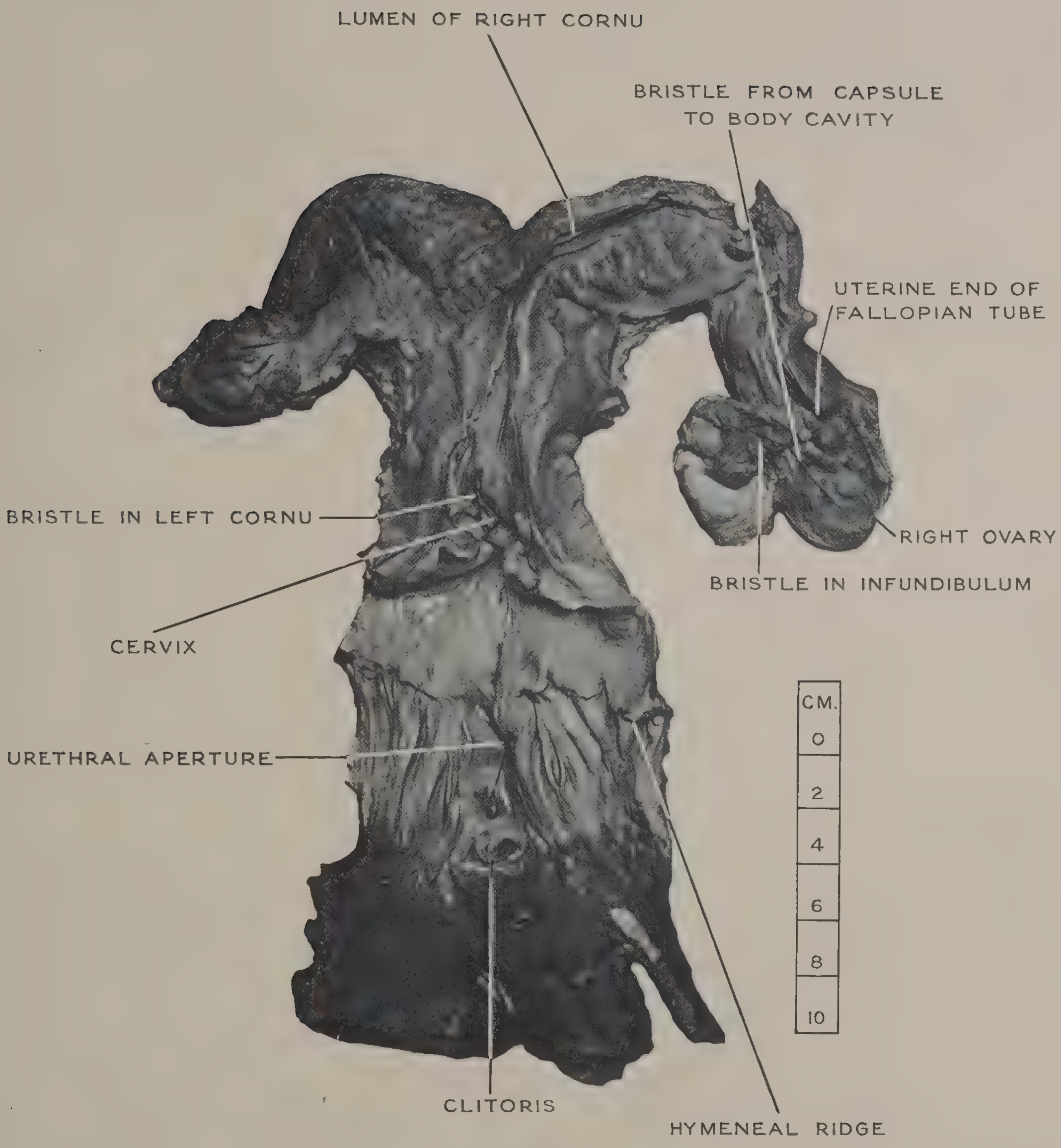
LUMEN OF RIGHT CORNU
BRISTLE FROM CAPSULE TO BODY CAVITY
UTERINE END OF FALLOPIAN TUBE
BRISTLE IN LEFT CORNU
RIGHT OVARY
BRISTLE IN INFUNDIBULUM
CERVIX
CM.
0
2
4
6
8
10
URETHRAL APERTURE
CLITORIS
HYMENEAL RIDGE

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PLATE XXXI

Photomicrographs of genitalia

Fig. 1. Seal No. 464. Inactive testis showing "teratocyst 2". × *circa* 100.

Fig. 2. Seal No. 471. Active testis. × *circa* 95.

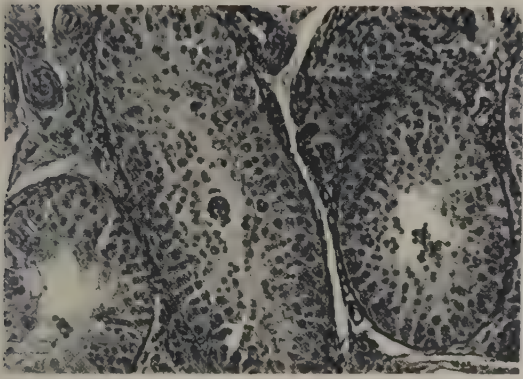
Fig. 3. Seal No. 450. Anoestrous uterus. × *circa* 95.

Fig. 4. Seal No. 448. Oestrous uterus. × *circa* 95.

Fig. 5. Seal No. 448. Oestrous uterus, showing mitoses. × *circa* 280.

Fig. 6. Seal No. 430. Postoestrous uterus. × *circa* 95.

Fig. 7. Seal No. 430. Postoestrous uterus. × *circa* 280.



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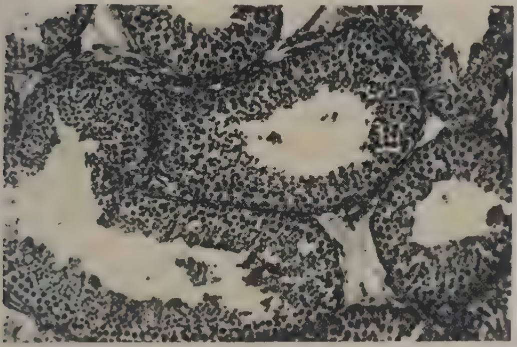

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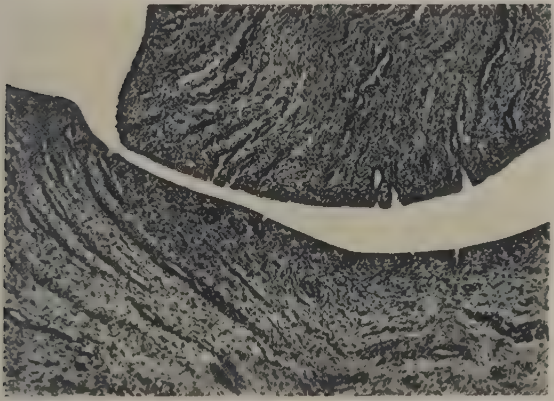

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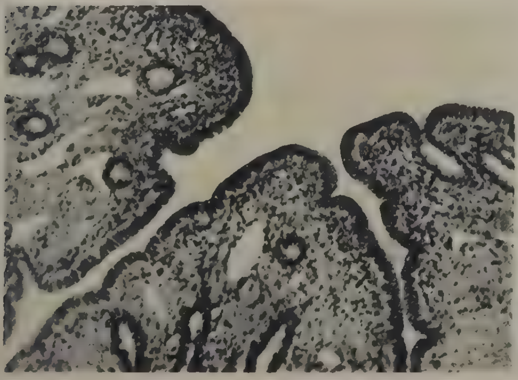

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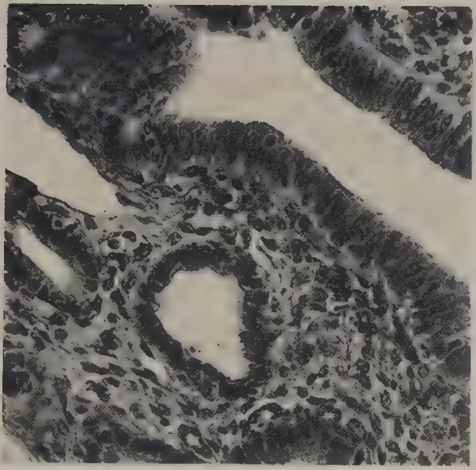

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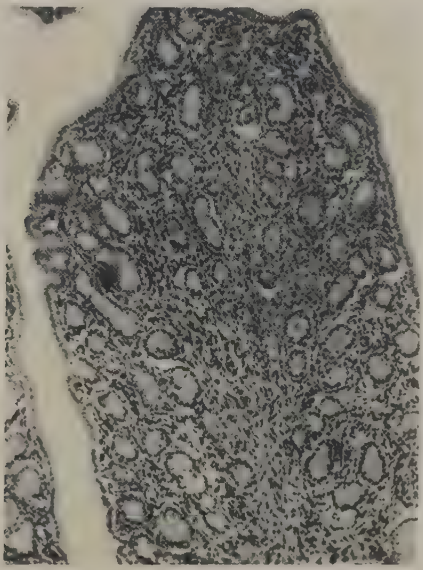

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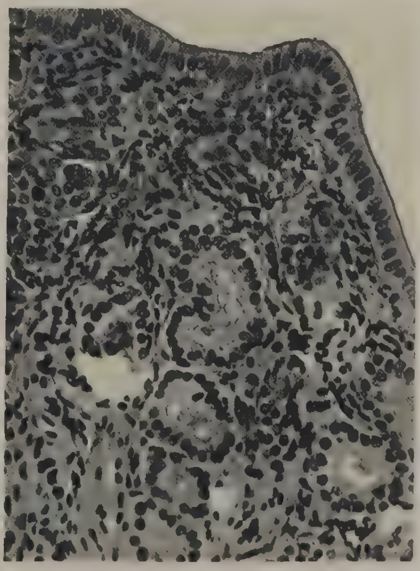

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PLATE XXXII

Photomicrographs of genitalia

Fig. 1. Pregnant seal No. 436. Sterile cornu of uterus. × *circa* 95.

Fig. 2. Pregnant seal No. 440. Sterile cornu of uterus. × *circa* 95.

Fig. 3. Pregnant seal No. 439. Sterile cornu of uterus. × *circa* 95.

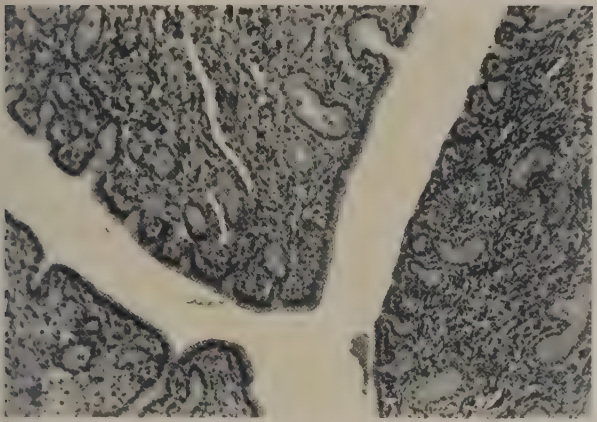
Fig. 4. Pregnant seal No. 477. Sterile cornu of uterus. × *circa* 95.

Fig. 5. Seal No. 450. Vagina, anoestrus. × *circa* 95.

Fig. 6. Seal No. 409. Vagina, earlier oestrus. × *circa* 95.

Fig. 7. Seal No. 406. Vagina, later oestrus. × *circa* 95.

Fig. 8. Seal No. 424. Vagina, postoestrus. × *circa* 95.



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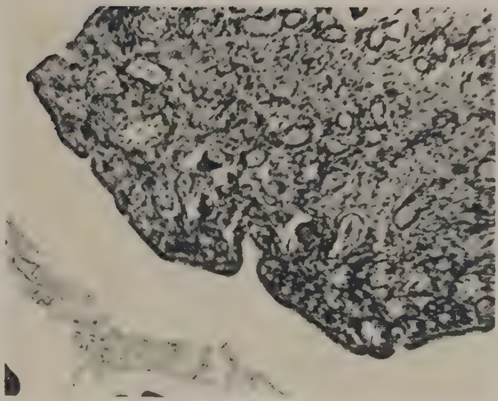

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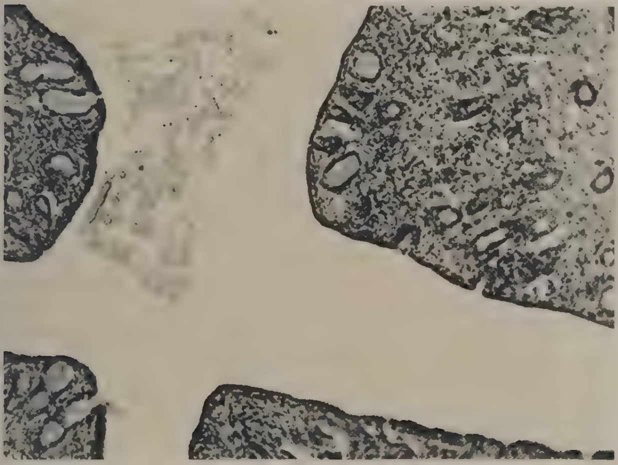

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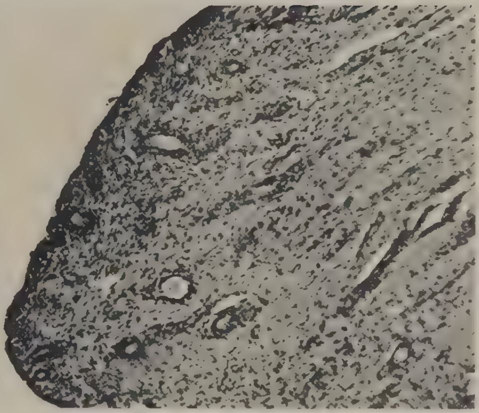

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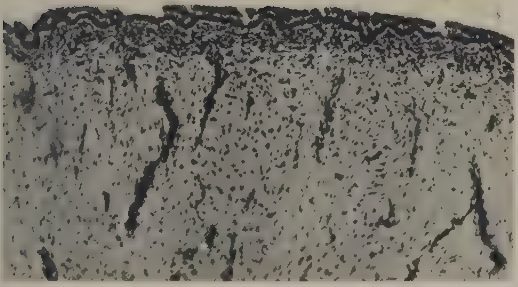

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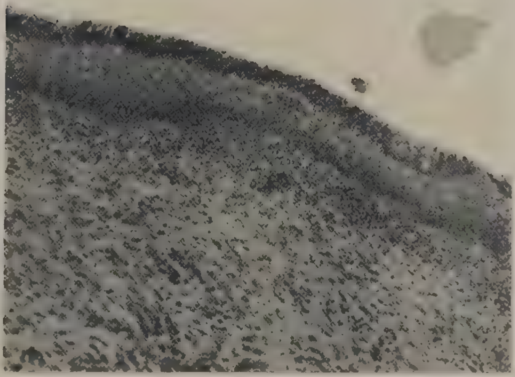

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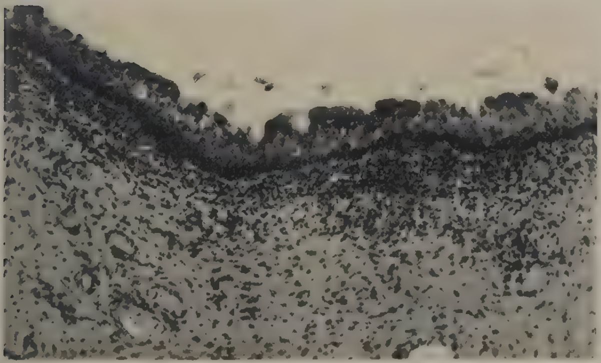

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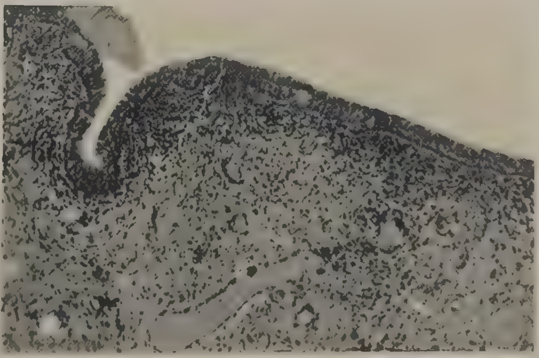

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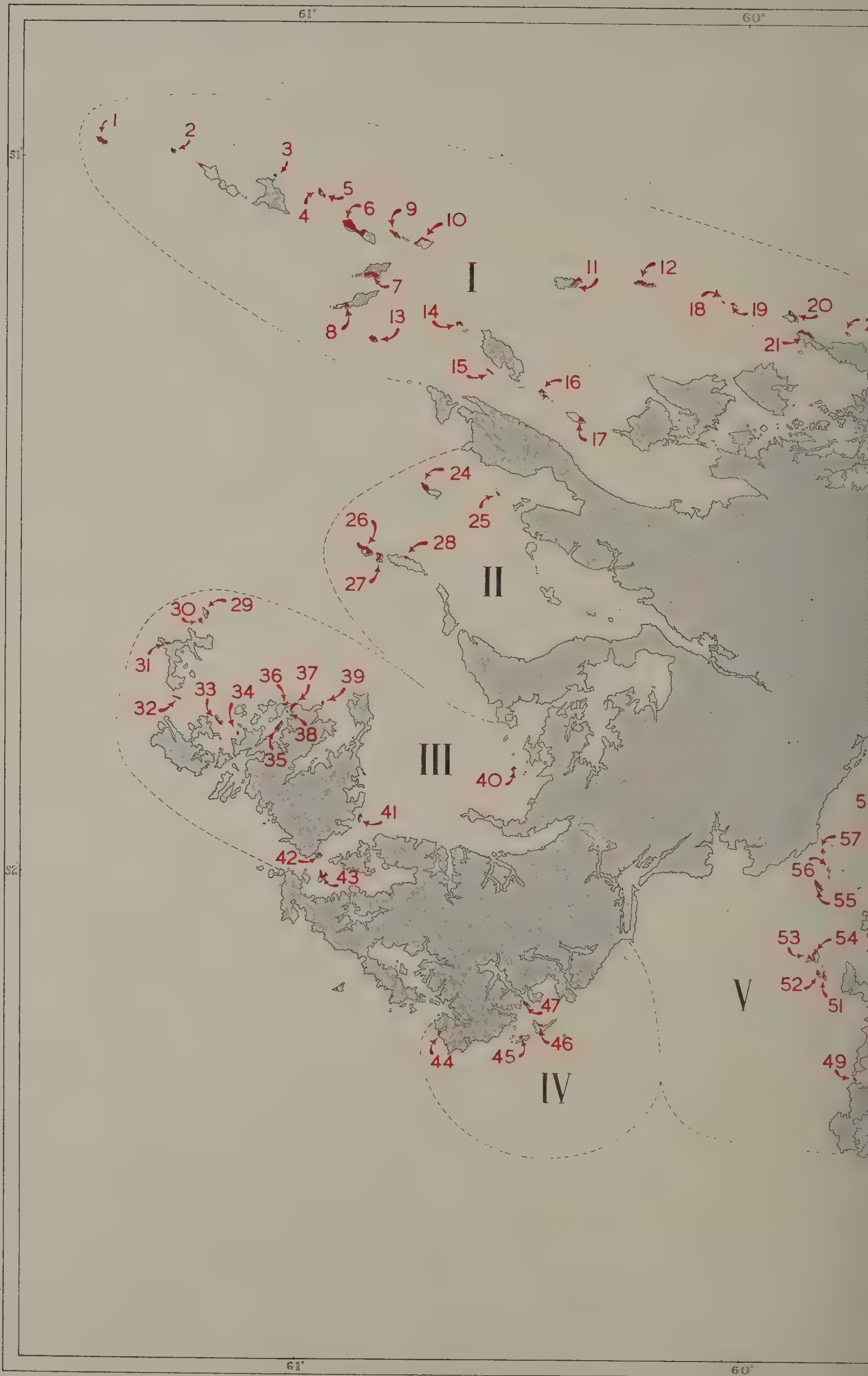
PLATE XXXIII

Map of the Falkland Islands, showing breeding rookeries of *Otaria byronia* (see p. 156)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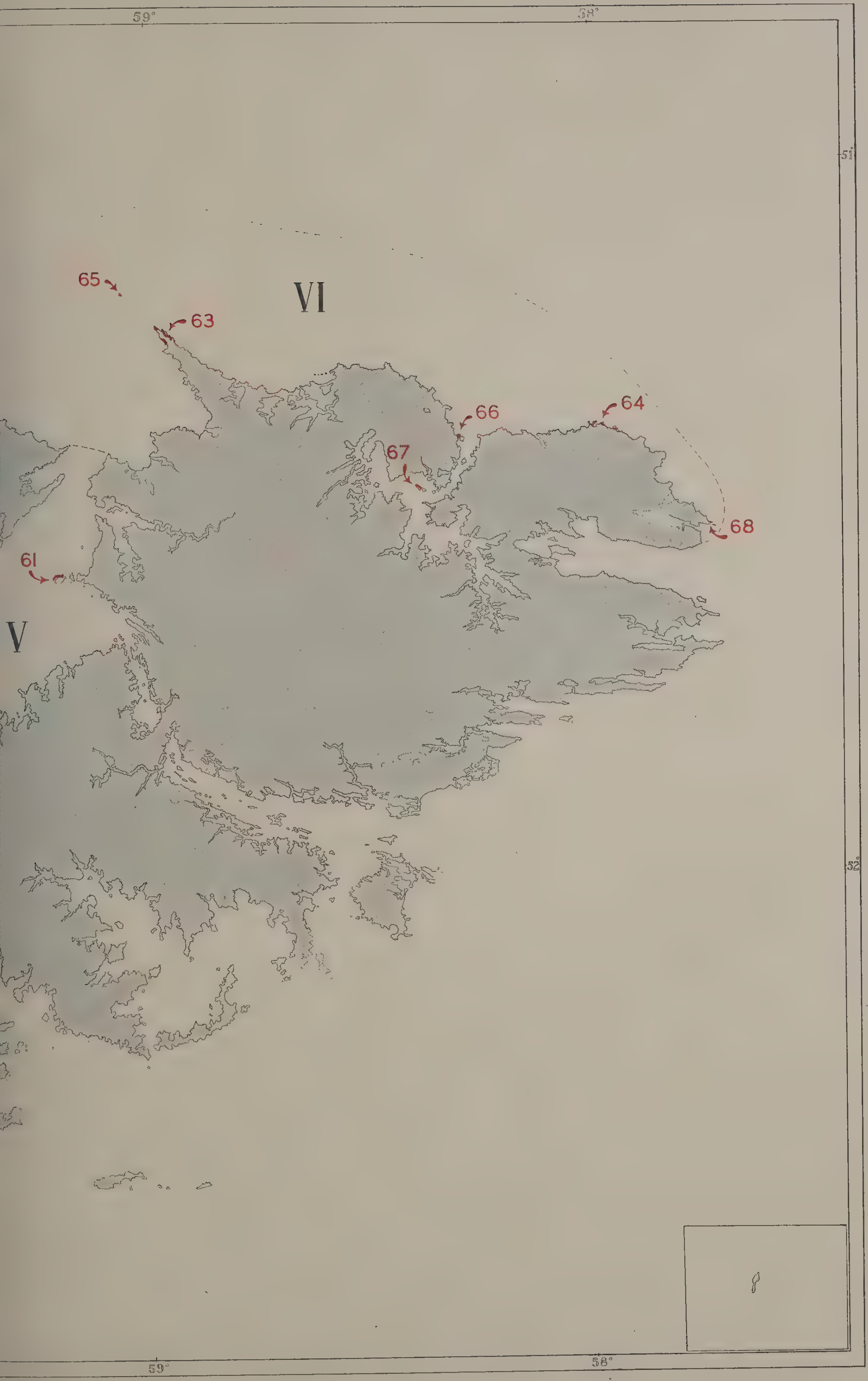
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[*Discovery Reports. Vol. XIX, pp.* 165–184, *Plates XXXIV–XXXVIII, May,* 1940]

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MACROBERTSON LAND AND KEMP LAND, 1936

By

GEORGE W. RAYNER

With

A REPORT ON ROCK SPECIMENS

By C. E. Tilley, F.R.S.

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MACROBERTSON LAND AND KEMP LAND, 1936

By George W. Rayner

(Plates XXXIV–XXXVII; Text-figs. 1–4)

DURING the southern whaling season of 1935–36 the R.R.S. 'William Scoresby', under the executive command of Lt.-Com. C. R. U. Boothby, R.N.R., was engaged in marking whales in the Southern Ocean between the meridians 0 and 100° E. In February, whilst the ship was making passage from the more easterly part of this area towards the west, very open conditions were found in the seas bordering the newly explored coasts of the Antarctic Continent between 75 and 55° E. Unfortunately, the exigencies of the whale marking programme did not allow time to be spent taking full advantage of these very favourable circumstances, but it was possible to add a little to our knowledge of this coast, especially of the part known as Kemp Land. In the short time available every opportunity was taken by Lt.-Com. Boothby and his officers to place this part of the coast as accurately as possible with the means at their command and to denote its more prominent features. Charts 2, 3 and 4 have been prepared from original charts by Lieut. A. F. Macfie, R.N.R.

The two landings were of short duration, but endeavours were made to obtain a representative suite of rocks at each place and to make whatever other observations were possible. The rocks collected have been described by Prof. Tilley, F.R.S., whose report is appended.

My thanks are due to Mr H. N. Dixon for identifying moss obtained at the second landing, to Dr H. R. Mill and Lt.-Com. R. S. Gould, R.N. (retd.), for assistance with the historical part of this report and to Dr N. A. Mackintosh for his help and encouragement.

Since the manuscript of this paper was completed the Royal Geographical Society has published a map (*Journ. Roy. Geog. Soc.* 1939), parts of which were drawn in consultation with myself, summarizing the course of exploration in the part of the Antarctic here discussed.

HISTORICAL

The landfall made by Kemp in 1833 in 66° S, 59½° E has long been known, but it has rested on little evidence and has lacked corroboration until recent years, when, however, ample justification has been forthcoming. In a note following a paper on the voyage of Balleny read by Charles Enderby to the Royal Geographical Society in 1839 the endeavours of the famous firm of Enderby Brothers to increase the existing knowledge of the Antarctic regions is fittingly mentioned, and Kemp Land is here included among the many discoveries of Enderby's master mariners. Kemp may at some time have been one of Enderby's masters but at the time of his discovery his vessel, the 'Magnet', was not in their possession; it was then owned, Lt.-Com. R. S. Gould, R.N., informs me, by one William Bennett of Rotherhithe and did not subsequently pass to the Enderbys' name.

The Admiralty archives contain a chart which entered the Hydrographic Office in May 1833 and on it the track of Kemp's brig from Kerguelen during December 1833 and the landfall are entered in manuscript along with the tracks of many other voyages of that period; the portion of this chart showing Kemp's track and notes is reproduced by Mawson (1935 *b*). It was on these two pieces of evidence that our knowledge of Kemp Land rested until 1930 when Sir Douglas Mawson, in the S.Y. 'Discovery', visited these regions and on 12 January, when proceeding westwards, sighted land in 66° 03′ S, 57° 43′ E. Kemp had on board his brig two chronometers giving different rates, and Mawson, calculating the position of Kemp's landfall from his chronometer No. 173 instead of No. 279, which apparently Kemp himself accepted, placed it about two and a half degrees to the westward and was of the opinion that the land sighted on 12 January 1930 was actually the same land that Kemp had seen in December 1833. To a wide bay in this vicinity he gave the name Magnet Bay after Kemp's vessel. The rest of Kemp Land, eastwards to 60° E, was charted during a seaplane flight made on 5 January and, according to a note on Mawson's chart, "adjusted to accord with later work". This later work was the exploration of MacRobertson Land and was carried out in 1931, adding a considerable length of new land to the Antarctic periphery. MacRobertson Land was considered to extend eastwards from Kemp Land to Cape Amery on the eastern side of the entrance to a large bight which was named the MacKenzie Sea. The 'Discovery' had advanced southwards in this bight to 68° 14′ S in longitude 70° 10′ E and Mawson states: "The Mackenzie Sea was charted from the seaplane at a height of 5500 ft."

During the course of their whaling operations, the Norwegian whalers had been in this region in January and February 1931 and their discoveries and names were later incorporated in the chart published by the Norsk Hvalfangernes Assuranceforening (1934). Land was sighted several times in quick succession by different observers and the following account is constructed from papers by Isaachsen (1931, 1932) and Lars Christensen's book *Such is the Antarctic* (1935).

On 12 January 1931 the whale catcher 'Seksern' (Capt. Brunvoll) in good visibility sighted land between 64° and 66° 34′ E; sketches were made. The next day this catcher is said to have reached the vicinity of Thorshavn Bukta, the Norwegian name later for Mawson's MacKenzie Sea, but the weather was bad and no further observations were possible. A few days later, on 19 January, the catcher Bouvet II (Gunner Reidar Bjerkö) proceeding east from 64° E saw land, and a sketch was made on board. On 20 January the catcher 'Bouvet III' (Gunner C. N. Sjövold) sighted land between 65 and 64° E with many islands and rocks lying up to 25 miles from the coast, and the next day, when weather-bound behind an iceberg, the mountains later named by Mawson, Scullin

Monolith, Murray Monolith, Mount Marsden, Mount Kennedy, etc. were seen. Two days later, 23 January, the 'Bouvet III' proceeded in a general south-easterly direction in poor visibility throughout the day until 2200 hr., when the ship stopped. The next morning, at 0200 hr., position given as 68° S, 74° E, during a short break in the thick weather the ship was seen to be in an ice bay, and beyond this, in a south-westerly direction, were a number of mountains. Two of these were considered to be volcanoes and named Sjövold Fjellene. At noon that day, 24 January, the position of the 'Bouvet III' was 65° 54′ S, 72° 44′ E. Soon afterwards another catcher, the 'Thorgaut' (Gunner Rolf Walter), proceeded westwards from 65° E and saw land stretching as far as 60° E. It was sketched as high land with many mountains, the coast at a distance of 20 or 30 miles showing many small islands and rocks.

Approaching from the eastward, Mawson, during a flight from 66° 29′ S, 76° 15′ E on 9 February 1931, saw an appearance of land in the extreme south which was later named Princess Elizabeth Land. Two days later, 11 February, Cape Darnley was sighted, and, as already mentioned, the MacKenzie Sea mapped from the air. This flight confirmed the existence of Princess Elizabeth Land and discovered the Munro Kerr Mountains, which are possibly the same as the volcanoes seen by Sjövold the previous month. Mawson continued westwards, following the coast, and on 13 February, landed at Scullin Monolith. Whether a landing was effected at Murray Monolith is not wholly clear from his accounts. From this time the coast was in sight continuously until 19 February when the homeward voyage commenced.

Hard on the stern of Mawson came another Norwegian whale catcher, the 'Torlyn' (Capt. Klarius Mikkelsen), despatched from the factory ship 'Thorshammer' by Consul Lars Christensen, doubtless with the object of verifying and extending the numerous reports of land made by his several catchers during the previous month. On 13 February, the day Mawson landed on Scullin Monolith, this catcher sighted Cape Darnley, cruised in the MacKenzie Sea and, in clear weather, reached land on 68° 50′ S, 71° E. The following day, 14 February, the 'Torlyn' rounded Cape Darnley and reached 68° S, 68° 10′ E at noon; she later passed Mawson's landing place, Scullin Monolith. Her position that evening is given as 68° 04′ S, 65° E, but snow setting in the next day she returned to her parent ship. The table below (p. 179) gives the chronology of the activities of Mawson and the Norwegians during the seasons 1929–31.

Isaachsen (1932) states that during the season 1930–31 several Norwegian whaling expeditions had also operated off Kemp Land, between 62 and 58° E. The coastline was sketched by Whaling Inspector Capt. Daehli from the Norwegian M/S 'Hilda Knudsen' and described by him as "an ice cliff coast, the ice rising inland to great heights and showing nunataks". Capt. O. Borchgrevink, in the factory ship 'Antarctic', favoured by clear weather and an open sea, executed some painstaking work off Enderby Land, his observations purporting to extend as far east as 59° E.

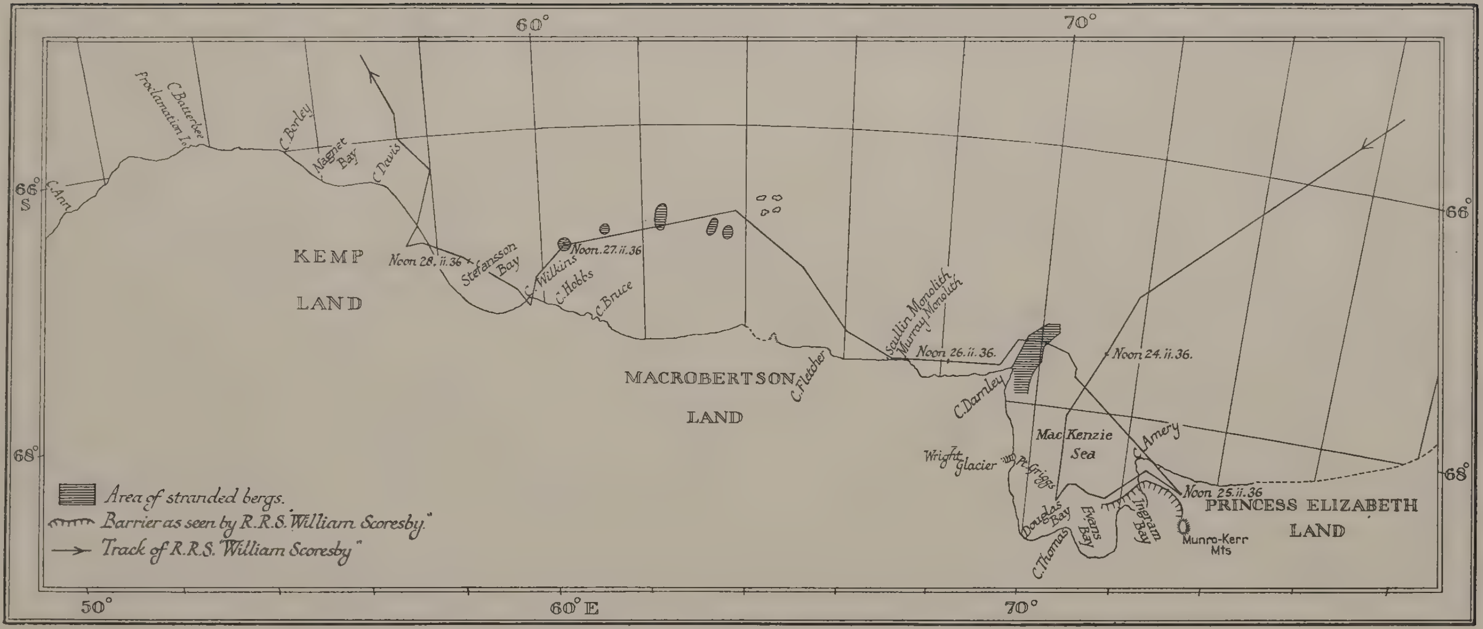
60°
70°
66° S
66°
68°
68°
50°
60° E
70°
C. Ann
C. Batterbee
Proclamation I.
C. Borley
Magnet Bay
C. Davis
KEMP LAND
Noon 28. ii. 36
Stefansson Bay
C. Wilkins
C. Hobbs
C. Bruce
Noon. 27. ii. 36
MACROBERTSON LAND
C. Fletcher
Scullin Monolith
Murray Monolith
Noon 26. ii. 36.
Noon 24. ii. 36.
C. Darnley
Mac Kenzie Sea
C. Amery
Wright Glacier
Pt. Griggs
Douglas Bay
Evans Bay
C. Thomas
Ingram Bay
Noon 25. ii. 36
Munro-Kerr Mts
PRINCESS ELIZABETH LAND
▤ Area of stranded bergs.
Barrier as seen by R.R.S. "William Scoresby."
→ Track of R.R.S. "William Scoresby"

Fig. 1. Coast of the Antarctic continent from 50 to 80° E, from Admiralty Chart No. 3171, showing the track of the 'William Scoresby', with noon positions, stranded bergs and barrier south of Cape Amery.

NARRATIVE

This was the extent of the knowledge of these regions when the 'William Scoresby' making passage from one whaling ground to another, sighted Cape Darnley, at 1345 hr. on 24 February 1936. The MacKenzie Sea appeared to be open and free from pack ice, the wind had been and was still from the south-east, so, with such promising conditions, the ship turned southwards. Weather conditions, however, rapidly deteriorated, and soon, with a full gale blowing, snow began to fall making progress very slow. The ship stopped for the night at 2100 hr., the position then being 68° 45′ S, 70° 42′ E, and here, although the wind was still rising, the seas had decreased and it was presumed that the ship had entered some shelter, probably afforded by the southern end of the bight. With the air temperature down to 18° F a sounding, giving no bottom at 800 m., and a series of hydrological observations down to 400 m. were made. During the night the wind increased to force 10 (Beaufort scale) and drift was to the north-eastwards.

The following morning, 25 February, brought much better conditions and the night's leeway was partly made good by proceeding southwards, after which the course was altered towards the east. A true ice barrier was sighted at 0605 hr. and was followed in easterly directions until noon. It varied in height from 90 to 160 ft. and was found to trend first north-eastwards, then east-south-eastwards and, when the ship turned away to the westwards at noon, south-south-eastwards. At this point, 68° 33½′ S, 73° 76′ E, with good visibility, no land could be seen in any direction, and to the east of the ice barrier, from 158° through east and north to 338°, was open water with a heavy swell and rough sea from the south-east. The most northerly point of the barrier passed was well south of Mawson's Cape Amery, and it would seem that this must lie further south than he has placed it. On the other hand, the barrier as found was considerably further north than that shown on the Norwegian chart, and occupied a mean position between the two previous renderings of the east side of the MacKenzie Sea. Lars Christensen (1938) visited this region again in the 7000 ton S.S. 'Thorshavn' during January 1937 and then found that "the barrier from Sandjefiord Bay northwards to Thorshavn Bay should be placed 12 nautical miles farther north"; thus bringing the Norwegian charting nearer to that of the 'William Scoresby'. That the final demarcation of the boundaries of the MacKenzie Sea must await further investigation is obvious. It is possible that Mawson's Cape Amery, which must have been part of a barrier, has become detached and floated away as an iceberg since the flight made on 11 January 1931. It is also possible that the 'William Scoresby' steamed partly around one of the exceptionally large icebergs which are occasionally met with in these waters and not along part of the fixed barrier, but under the conditions then prevailing the Munro Kerr Mountains should have been seen if they are in Mawson's position. That these lie much further south and are the same as the Sjövold Fjellene would seem to be established by subsequent Norwegian work (Christensen, 1937).

Having abandoned her eastward course the 'William Scoresby' steamed for Cape Darnley and that evening (25 February) a station was made in 300 m. at the mouth of

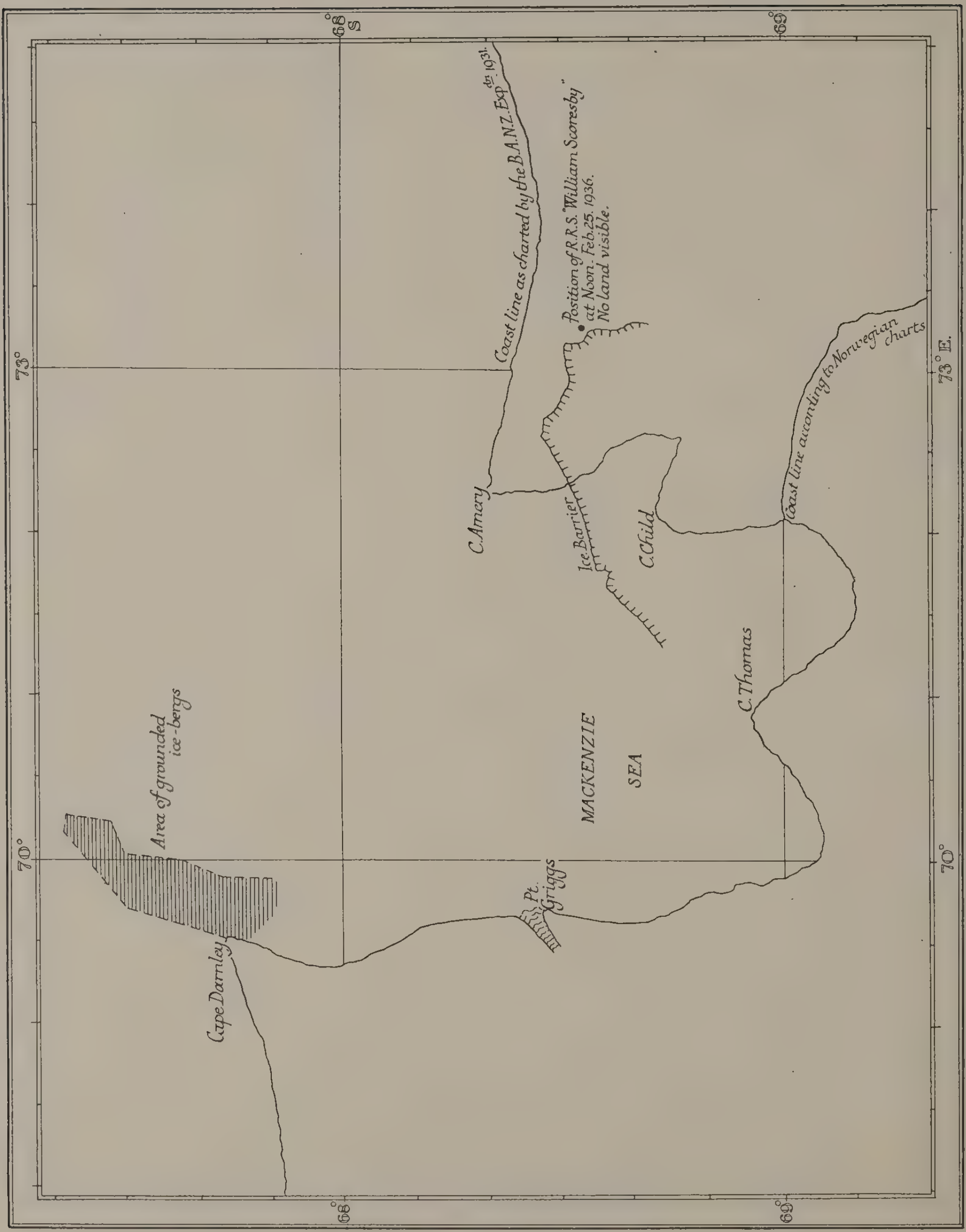
68° S
69°
73°
70°
73° E.
70°
68°
69°
Coast line as charted by the B.A.N.Z. Expdn. 1931.
Position of R.R.S. "William Scoresby" at Noon. Feb. 25. 1936. No land visible.
C. Amery
Ice Barrier
C. Child
Coast line according to Norwegian charts
C. Thomas
MACKENZIE SEA
Area of grounded ice-bergs
Pt. Griggs
Cape Darnley

Fig. 2. The MacKenzie Sea, coastline according to Mawson and according to Norwegian observations.

the MacKenzie Sea and due north of the station of the previous night. The following morning a very dense area of grounded bergs was encountered off Cape Darnley, such as the catcher 'Torlyn' met in February 1931. These were packed so closely that it was necessary to run some way to the north to find a channel through them. Having cleared this obstruction the ship returned to within sight of the coast and proceeded westwards, passing through a large extent of pancake ice in the early stages of its formation. To the east of Murray Monolith bare rock supporting an ice cliff was observed at sea level.

At Scullin Monolith a landing was made and almost the whole ship's company went ashore. Accounts of this and a second landing further west are given below (pp. 176–178). Steaming through the night, from this point, a detour to the north was necessary to avoid pack-ice off Cape Fletcher and the many off-lying islands and rocks present along this coast. Clearly defined areas of closely packed bergs, believed to be grounded, were encountered in the positions shown on the chart (Fig. 1) and soundings of 150 fathoms and 75 fathoms made nearby.

Land was again sighted to the southward early on the morning of 27 February, but it was not until Sheehan Nunatak was visible and, when near enough to discount the effects of mirage, seen to be wrongly represented on the chart, that course was altered inshorewards. The ship now steamed southwards through an archipelago consisting of many ice-free rocky islands and islets ranging up to 250 ft. in height and extending northwards for about 13 miles from Sheehan Nunatak. Sheehan Nunatak was considered to be the most conspicuous of a group of larger islands closer inshore (Figs. 3 and 4). South and west of Sheehan Nunatak a bay was found running southwards for about 5 miles to 67° 26′ S in 59° 40′ E, where it was about 3½ miles wide (Fig. 4). Around this bay, William Scoresby Bay, were steep rock headlands and snow-free hills up to about 700 ft. in height; between them the continental ice came down to the sea in greater or smaller ice-cliffs. Soundings of 6½ to 20 fathoms were obtained close in shore and of 85 fathoms with a bottom of green mud, and 100 fathoms, no bottom, in the middle of this bay. The number of rocks observed awash suggests that the bottom is very irregular, and it is, no doubt, of a morainic character. In spite of this no suitable anchorage was found, although the bay affords excellent shelter in any weather, and many easy landing places. A landing was made on Bertha Island, which at the time was thought to be the mainland.

The west coast of the bay runs almost due north to Cape Wilkins (Cape Hearst in Mawson's charts, *Journ. Roy. Geog. Soc.*), and the following day, 28 February when the ship proceeded, a similar bay was found to lie to the west of this point, but was not entered: this was considered to be Mawson's Stefansson Bay. Continuing, the coast was found to trend north-westwards to a cape in 67° 05′ S, 59° 00′ E, and from this headland, which formed the eastern extremity of a shallow bight, the 'William Scoresby', cruising along from 3 to 8 miles offshore, was able to observe the coast for a distance of about 40 miles continuing the general east and west trend of MacRobertson Land. Throughout this length it retained the same rocky character, with bold headlands rising, dark and free of snow, to about 500 or 600 ft., between which were small pocket-

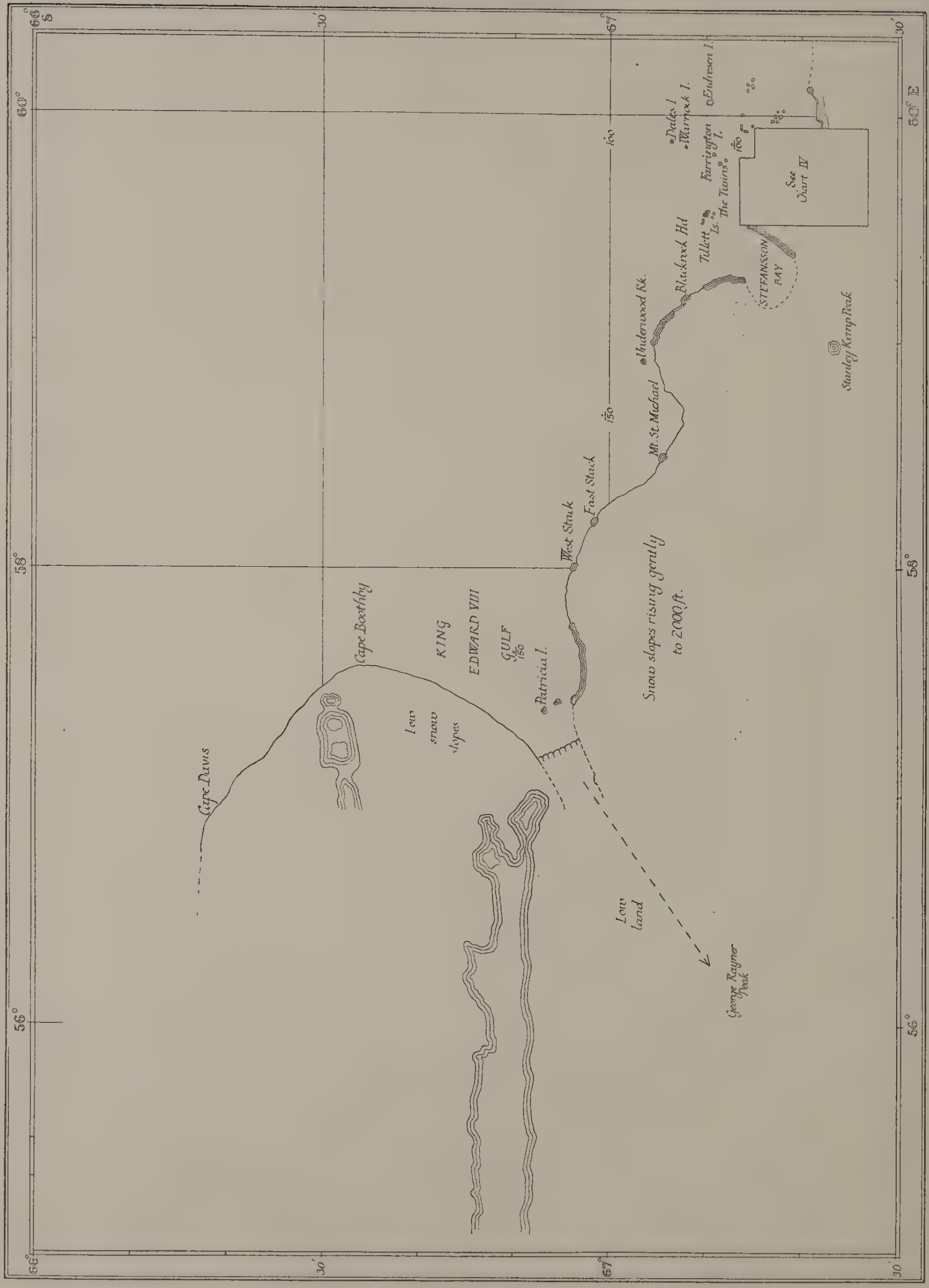
Cape Davis
Cape Boothby
Low snow slopes
KING EDWARD VIII GULF
Patricia I.
West Stack
East Stack
Mt. St. Michael
Underwood Rk.
Blacknock Hd
Tullett Is.
The Twins
Farrington I.
Dalks I.
Warnock I.
Eukeson I.
STEFANSSON BAY
See Chart IV
Stanley Kemp Peak
Snow slopes rising gently to 2000 ft.
Low land
George Rayner Peak
66° S
30'
67°
30'
60°
58°
56°
60° E

Fig. 3: Kemp Land from Sheehan Nunatak to Cape Davis. For inset see Fig. 4.

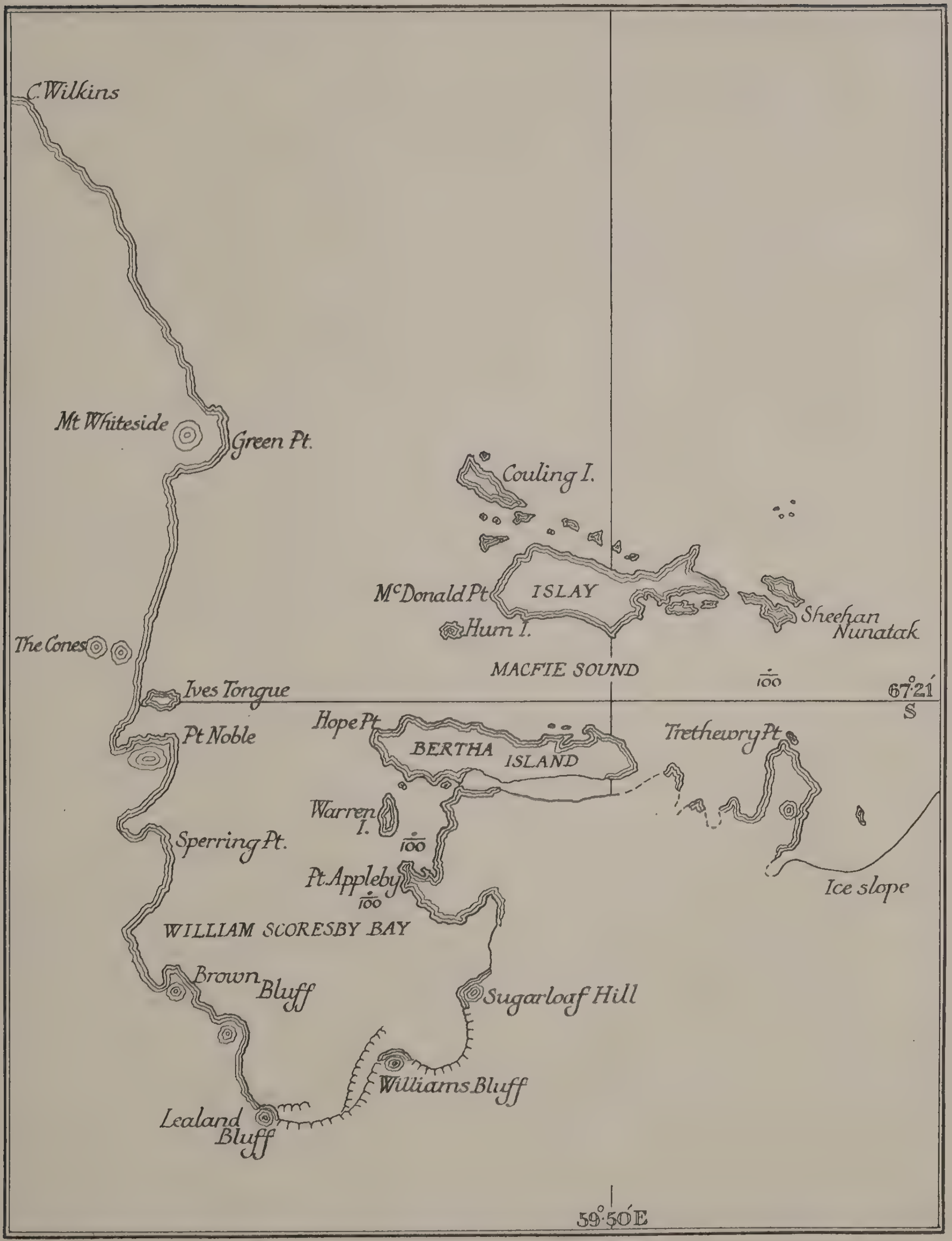
C. Wilkins
Mt Whiteside
Green Pt.
Couling I.
McDonald Pt.
ISLAY
Hum I.
Sheehan Nunatak
The Cones
MACFIE SOUND
100
Ives Tongue
67°21′ S
Hope Pt.
Pt Noble
BERTHA ISLAND
Trethewry Pt.
Warren I.
100
Sperring Pt.
Pt. Appleby
100
Ice slope
WILLIAM SCORESBY BAY
Brown Bluff
Sugarloaf Hill
Williams Bluff
Lealand Bluff
59°50′E

Fig. 4. William Scoresby Bay, enlarged from Fig. 3.

like bays, running into the land or cliffs, bringing the continental ice to the sea. Southwards the continental ice sloped gently upwards to an even skyline at a height of about 2000 ft., and although visibility was excellent no distant mountains except Stanley Kemp Peak were seen to break this horizon.

Westwards of this stretch of land the coast took an abrupt turn, now running almost north-north-eastwards with snow slopes coming down to the sea without visible outcrops; in this way a deep funnel-shaped bay, which seemed to run far into the land, was formed. This gulf apparently terminated in an ice barrier, and beyond it, at a very great distance in a south-westerly direction, could be seen a prominent peak (George Rayner Peak), possibly the northern end of a mountain range, for beyond it other peaks could be discerned. Between this peak and the barrier at the head of the gulf the (presumably) ice-covered land was low and flat, reaching to the horizon. On the north side of the gulf ice-covered foothills rose inland to a mountain range running almost east and west and culminating when about 50 miles from the coast in peaks possibly ranging up to 6000 ft. in height; these may be Borchgrevink's Akerfjellene. From a cape in about 66° 34′ S, 57° 34′ E the coast-line turned north-westwards to Cape Davis and inland from this could be seen foothills terminating Mawson's Nicholas Range. Icebergs and pack-ice were encountered along this coast, which was now left for the search of whales in the open ocean.

SCULLIN MONOLITH

Scullin Monolith is a crescent-shaped massif rising to 1200 ft. or more and enclosing a north-facing cove whose entrance is about 1½ miles across. The upper parts are everywhere precipitous, but the lower 200–300 ft. slope steeply in many parts and are strewn with boulders and large stones, among which lodges a coarse loose grit weathered from the country rock. Elsewhere scree slopes occupy the lower parts or the rock face falls sheer to the sea. Very little snow was to be seen resting on this seaward face at the time of this visit.

The landing was made near the eastern tip of the crescent and about three hours were spent ashore. The part of the massif examined consists of warm reddish brown gneiss containing many small garnets. For the most part, and on all the higher surfaces, the rock has weathered with a sound even surface, but along some of the lower ridges the rock is decayed and rotten. Near sea level dark-coloured finer textured rock was found in dyke-like formation.

An ascent to a height of 700–800 ft. was made and it could be seen that the south-eastern face of the massif is wholly precipitous, falling sheer to the continental ice, which breaks against it in a very heavily crevassed condition.

The rock is a nesting-place for many of the Antarctic birds. Over the lower slopes of the area examined Adélie penguins (*Pygoscelis adeliae*) seemed to occupy every obtainable stance. At the time of this visit the young were fully grown and undergoing their last moult, but judging by the remains strewn everywhere the rate of mortality in this rookery is very high. Skua gulls (*Catharacta skua*) were present and a sea leopard

(*Hydrurga leptonyx*) was swimming about the rocks below. The upper crags held the nesting sites of Silver Grey (*Priocella antarctica*), Antarctic (*Thallassoica antarctica*) and Snow Petrels (*Pagodroma nivea*) and possibly of the Wilson Petrel (*Oceanites oceanicus*). Nests of the Silver Grey and Antarctic Petrels were situated on the higher ledges and contained nestlings; the young of the Antarctic Petrel were almost ready to leave the nest, but those of the Silver Grey were only half fledged and still covered with down.

BERTHA ISLAND

This island was first thought to be part of the mainland, but after landing it was found to be separated from the mainland by a narrow channel varying in width from 100 yds. to ¼ mile, and at the time frozen over for much of its length. Beyond it the continental ice sloped down to sea level between two rocky headlands. The main features of this district follow the cardinal points of the compass and the island exhibits the same orientation, its long axis, in length about 3 miles, extending roughly east and west. It may be described as consisting of a series of ridges, running roughly north and south, normal to the long axis of the island, between valleys connected by saddles running east and west beneath rounded rocky eminences. The island is low to the east, where the landing was made, whence it rises steadily ridge by ridge to about 400 ft. at the western end, there falling sharply to the sea.

The rock of the island is lightish brown in hue, fine grained and gneiss-like, containing many intrusions of a darker rock varying in width from a few inches to several feet. A most striking feature was the extraordinary wealth of garnets contained in both rocks and weathered out into the sands and grits which occurred extensively. The manner in which these rocks have weathered was interesting and remarkable. Some of the rocks show a normal form of exfoliation, but the greater part exhibits the effect of extreme wind erosion, the rock surface being etched and pitted into a honeycomb structure. In places this erosion is carried to an extreme degree, the holes formed extending in depth to a full arm's length or cutting the rock into grotesque and fantastic shapes, whilst boulders were seen consisting merely of a thin fretted shell.

The island was remarkably free of snow; only a few isolated patches, not older than the previous winter, were encountered. In favoured positions on the northern slopes patches of moss were to be found. Specimens collected have been identified by Mr H. N. Dixon as *Bryum antarcticum* Hook. f. et Wils., a species widely distributed in the Antarctic, but not extending into the sub-Antarctic islands. Mr Dixon writes: "The specimen is of considerable interest as it shows a considerable transition between two or three forms, and confirms my suggestion (*Australian Antarctic Expedition*, *Sci. Rep.* Ser. C, vol. VII, pt. I, p. 7) that several of the antarctic plants described as species are but forms of this variable one."

Pools of fresh water existed in the hollows among the hills and had been more extensive and numerous. They were frozen over at the time of the visit, but in one considerable vegetation could be seen through the clear ice. Some of this was collected and it is evidently a Cyanophyceous sheet such as Fritsch (1912) describes, but it has not yet been examined.

Weddell seals (*Leptonychotes weddelli*) were plentiful on the south side of the island and a few Emperor (*Aptenodytes forsteri*) and Adélie Penguins (*Pygoscelis adeliae*) were seen, but other birds were absent. Emperor Penguins were seen again the following day at sea off the Kemp Land coast. During the night, whilst the ship was lying close to the island, there was a remarkably fine display of the Aurora.

SUMMARY

1. The course of exploration of the coasts of those parts of the Antarctic continent known as Kemp Land and MacRobertson Land is outlined.

2. A narrative of the five days cruise of the R.R.S. 'William Scoresby' along these coasts in 1936 is given, and parts of the Kemp Land coast, hitherto unexplored, are described.

3. Accounts are given of landings made at Scullin Monolith, MacRobertson Land and Bertha Island, Kemp Land.

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CHRONOLOGICAL TABLE

	Mawson’s Explorations in the Regions of Kemp Land and MacRobertson Land in S.Y. ‘Discovery’		Norwegian Explorations in the Region of Kemp Land and MacRobertson Land
1929 26 Dec.	Noon position 66° 57′ S, 71° 57′ E. Appearance of land considered to be produced by mirage seen to south-west at 7.2 P.M. and onwards. (This would be Cape Darnley, etc.)		
27 Dec.	Land blink in same direction.		
31 Dec.	Flight from 66° 10′ S, 65° 10′ E. At 5000 ft. distant undulating ice slopes seen in the south—considered to be ice-covered land. Distant to the south-west black objects considered to be rocky islands surrounded by grounded bergs.		
1930 4 Jan.	In 66° 35′ S, 61° 17′ E, depth 550 fathoms, shelving bottom, from masthead land ice and nunataks seen to be miraged up along the southern horizon.		
5 Jan.	Flight from 66° 30′ S, 61° 08′ E. At 4000 ft., 30 miles from ship great extent of coast line of high land extending east and west, many rocky peaks and ranges seen up to 80–90 miles away.		
1931		1931 12 Jan.	‘Seksern’ (Brunvoll) in good visibility sees land between 64° and 66° 34′ E and makes sketch—photographs lost.
		13 Jan.	‘Seksern’ (Brunvoll) reaches Thorshavn Bay (MacKenzie Sea)—bad weather, no further observations.
		19 Jan.	‘Bouvet II’ (Reidar Bjerkö) goes east from 64° E. Sketch made of Gustav Bull Mountains and others to east.
		20 Jan.	‘Bouvet III’ (Sjövold) sights Lars Christensen Land (MacRobertson Land) between 65 and 64° E, also many islands and skerries 25 miles from the coast in a south-easterly direction.
		21 Jan.	‘Bouvet III’ (Sjövold), weather bound behind an iceberg, sees Torlyn (Murray Monolith), Mikkelsen (Scullin Monolith) and Gustav Bull Mountains.
		23 Jan.	‘Bouvet III’ (Sjövold) proceeds south, east, then south-east to south-south-east throughout day—foggy. At 2200 hr. has passed Thorshavn Bay (MacKenzie Sea)—stops, suspecting land.
		24 Jan.	‘Bouvet III’ (Sjövold), at 0200 hr. weather clears, position 68° S, 74° E in an ice bay, sees many mountains in a south-westerly direction, but only for 10–15 min. *Immediately after above.* ‘Thorgaut’ (Rolf Walter) proceeds westwards from 65° E, sees western part of Lars Christensen Land (MacRobertson Land) to about 60° E—high land with many mountains, coast, 20–30 miles distant, shows many small islands and rocks.
9 Feb.	Flight from 66° 29′ S, 76° 15′ E. At 5700 ft. appearance of ice-covered land seen in extreme south (later named Princess Elizabeth Land).		
10 Feb.	Short flight, visibility poor, no results.		
11 Feb.	Cape Darnley sighted, MacKenzie Sea entered. Flight in afternoon follows coast for some distance (west side of MacKenzie Sea) and maps MacKenzie Sea, including Cape Amery. Confirms Princess Elizabeth Land and sights Munro Kerr Mountains. ‘Discovery’ now follows MacRobertson Land coast.		
		12 Feb.	‘Torlyn’ (Klarius Mikkelsen) leaves Fl/K. ‘Thorshammer’ in 67° 03′ S, 73° 44′ E and proceeds southward into pack.
13 Feb.	Landing on Scullin Monolith.	13 Feb.	‘Torlyn’ (Klarius Mikkelsen) cruises in open water, soundings 20 fathoms (gr. m.) and 170 fathoms (r), enters Thorshavn Bay (MacKenzie Sea) at 68° 30′ S, 70°–71° E. In clear weather reaches land at 68° 50′ S, 71° E. Sights high land, Bjerkö Odden (Cape Darnley) 1500–2000 ft., terminating in ice barrier 300 ft. high—follows barrier north-north-westerly distant 3–8 miles. Mikkelsen makes landing at 68° 10′ S, 69° E.
14 Feb.	Bad weather.	14 Feb.	‘Torlyn’ (Klarius Mikkelsen) enters bay with bergs, shore bare in places, barrier low and deeply fissured. During morning passes through very dense mass of bergs, extending north-easterly, clearing near Bjerkö Odden (Cape Darnley) gives 78 fathoms (r). Noon position 68° S, 68° 10′ E, sounding 48 fathoms. In afternoon passes Torlyn Fjell (Murray Monolith), Klarius Mikkelsen Fjell (Scullin Monolith), etc., between 68° S, 66° 30′ E and 68° S, 65° E, at a distance of 35 miles. Evening position 68° 04′ S, 65° E, sounding 100 fathoms (r).
		15 Feb.	‘Torlyn’ (Klarius Mikkelsen) in snow, returns to Fl/K. ‘Thorshammer’ off Enderby Land.
18 Feb.	Landing on Cape Bruce.		
19 Feb.	Departure for Australia. Coast in sight continuously from 11 Feb. to this date.		

ROCKS FROM MACROBERTSON LAND AND KEMP LAND, ANTARCTICA

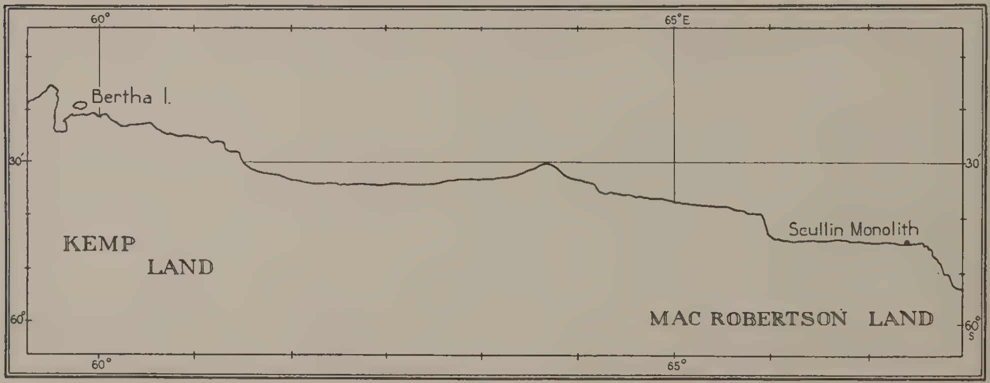
By C. E. TILLEY, B.Sc., Ph.D., F.R.S.

(Plate XXXVIII; Text-fig.)

The R.R.S. 'William Scoresby', during its investigations in Antarctic waters in 1936, made landings on the Antarctic coast at Scullin Monolith (MacRobertson Land) and near Sheehan Nunatak (Kemp Land), lying some 160 miles further west. Rock specimens now submitted to the writer for examination were collected from both these points by Mr G. W. Rayner, who has also provided a brief account of their field relations.

SCULLIN MONOLITH

In 1931 the B.A.N.Z. Antarctic Research Expedition made landings on MacRobertson Land at Cape Bruce and at Scullin Monolith, 150 miles further east. Brief descriptions of the rocks collected by this Expedition have already been published.[1] In that collection the locality of Scullin Monolith was represented by two igneous gneisses of granitic composition—quartz-microperthite gneisses carrying garnet, biotite and smoky quartz.



The 'William Scoresby' collection comprises about a dozen specimens all of which are of igneous origin and the majority acidic and gneissic in character. The dominant type is a coarse grained *quartz microperthite gneiss* with garnet and biotite as the chief ferromagnesian constituents. Some of them carry large porphyritic crystals of microperthite an inch in length. Primary foliation, which is evident in many of the specimens, is made visible by the orientation and distribution of biotite, and gneissic structure is strikingly displayed in some specimens by bands of dark smoky quartz. In these features the rocks present similarity with the granite-gneisses carrying conspicuous smoky quartz already described from the Cape Bruce area.[1] Hypersthene ranking only as an accessory is recorded from one specimen carrying both biotite and garnet.

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[1] *B.A.N.Z.A.R.E. Reports*, 1937, Vol. II, Pt 2, pp. 17–26.

Of other constituents plagioclase felspar is the chief. Always subordinate to microperthite its composition ranges from oligoclase-andesine to an andesine with the same range of refringence as quartz. The plagioclase constituent of the microperthite appears in two forms, the one the normal fine interpositions and the other as spindles and drops less regularly arranged and having the composition of an oligoclase-andesine. These features recall the microperthite textures met with so commonly in the mangerite-charnockite series of rocks. Antiperthite on the other hand is rare but a minor development of myrmekite textures is seldom absent. Garnet is typically xenomorphic with sieve texture, the enclosures being commonly quartz or biotite. In one specimen the enclosures include a green spinel, the significance of which has been commented upon in discussing the rocks from Cape Bruce.[2]

Two of the rocks falling within the group now described and distinguished by a finer grain are reported to occur in dyke-like masses cutting coarse grained varieties. Apart from specimens of quartz veins carrying garnet and microperthite, the only other distinctive rock type is represented by a *hornblende-norite* which, however, is not recorded in place. In addition to the dominant hypersthene, labradorite and greenish brown hornblende, the last of which tends to be moulded on the plagioclase, accessory augite and biotite are present. A sub-parallel orientation of the elongate minerals hypersthene, hornblende and biotite imparts a distinctive texture to the assemblage.

SHEEHAN NUNATAK AREA (KEMP LAND)

The rocks collected from this area come from Bertha Island, south-west of Sheehan Nunatak. This island, situated in lat. 67° 22′ S, long. 59° 50′ E, is separated from the mainland by a narrow channel of frozen water varying in width from a hundred yards to a quarter of a mile. The collection submitted by Mr Rayner consists of ten specimens which show greater variety of composition than the suite from Scullin Monolith (MacRobertson Land).

The chief rock type of the island is a *garnet-hornblende-microperthite-quartz gneiss* containing accessory clinopyroxene and hypersthene. The specimens are medium-grained foliated types weathering to a light brown colour, the foliated character being brought out by streaks of dark minerals (chiefly hornblende). In slice the constituents are seen to be quartz, microperthite, subordinate plagioclase (andesine)—the grains tending to be elongated in the foliation plane, the chief ferromagnesian minerals being green-brown hornblende and garnet. Of the pyroxenes, a green monoclinic hedenbergite exceeds hypersthene in amount. Undulose extinction in felspars and the occurrence of granulitic zones carrying fine myrmekite at microperthite grain boundaries is characteristic.

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[1] *B.A.N.Z.A.R.E. Reports*, 1937, Vol. II, Pt 2, p. 22.

[2] *Ibid.* p. 23.

Two other specimens in their richness in almandine garnet are reminiscent of the gneisses of the Cape Bruce area. They are: (1) a *microperthite-quartz gneiss* carrying biotite, garnet and accessory xenotime; (2) a *quartz plagioclase (andesine) garnet gneiss* with spinel enclosures in the garnet. Both these rocks are of igneous origin.

The remaining rocks are of more basic character. They include:

(1) *Hypersthenite* and *garnetiferous hypersthenite* reported as forming a small outcrop 15–20 ft. in diameter towards the western end of Bertha Island. In these the coarse-grained hypersthene has translucent exsolution lamellae of ilmenite and accessories include plagioclase, biotite and opaque ores including magnetite, pyrrhotite, and chalcopyrite.

(2) *Mangerite* passing into *quartz norite*. This is a coarse-grained banded rock of variable composition containing hypersthene, augite, plagioclase (andesine-antiperthite) and microperthite with andesine interpositions characteristic of the mangerite type of rock. Hornblende is in variable amount and in one band is the dominant coloured mineral. Garnet is sporadic. In the absence of field data the significance of this variable composition is difficult to assess.

(3) Finally, a group of basic rocks recorded as bands in the country rock, examples of which are reported to range in width from a few inches to several feet.

Three rocks of this type are available for study. They may be described as *metamorphosed gabbros or norites* exhibiting as they do clear signs of secondary changes. The principal constituents are augite, hypersthene, hornblende and labradorite, while there is a very variable content of late formed garnet. They all show some features of foliation usually in the orientation of elongate crystals of the chief ferromagnesian minerals, while signs of stress are evident in undulose extinction and a patchy and interrupted development of twinning in the felspars. As a group one distinctive feature is the occurrence of a diablastic intergrowth of plagioclase and pyroxene (augite) fringing and often embaying the hornblende crystals. (Plate XXXVIII, figs. 1 and 2.)

Garnet noted above as a variable constituent appears chiefly in the form of coronae around (*a*) hypersthene, (*b*) augite, (*c*) hornblende, (*d*) iron ores, usually then abutting against plagioclase felspar. But garnet may also appear isolated within felspar or as grains in an augite-garnet granulitic zone, surrounding or crossing larger pyroxene crystals. The commonest enclosure in the small garnets is monoclinic pyroxene forming a minute vermicular intergrowth and in some examples garnet development is accompanied by the separation of quartz. The presence of quartz is especially characteristic of the coronae around augite and hypersthene, and the mineral then appears as a narrow zone intervening between the pyroxene and the garnet (Plate XXXVIII, figs. 3 and 4). The variable development of garnet in one and the same specimen is strikingly revealed in a rock showing one face with a coarse development of hornblende (± augite) and plagioclase (± quartz) which passes sharply into the main body of the rock. Sections taken at right angles to this face show that garnet increases in amount as this face is approached. Sporadic in its development at points most remote (3 in.) it becomes an abundant constituent in the associations already indicated close to the selvedge of coarse structure (cf. Plate XXXVIII, figs. 2, 3 and 4).

Field data available concerning the rocks under discussion do not permit unequivocal decision whether they are to be regarded as bands forming dykes in the acid gneisses or band-like *inclusions* of earlier date. The micro-structures and mineralogy indicate clearly, however, that they are metamorphosed gabbros and there can be little doubt that they have suffered transformations while they were essentially solid.

The development of garnet as a corona mineral intervening between pyroxene and felspar and in granulitic aggregates of pyroxene is a familiar phenomenon which has been the subject of much study since Kemp[1] first described the garnetiferous gabbros of Essex County in New York State. The literature contains discussions of the chemical mechanism of garnet formation to which reference is now directed.[2]

The sporadic development of this mineral and its distribution in specimen 4 indicated above suggest:

(1) If these rocks are dykes then the changes produced, especially the development of reaction rims, may be a deuteric transformation following closely upon consolidation by the passage of liquid or fugitive constituents emanating from the magma chamber from which the dykes were erupted. Such an origin has been ascribed to the garnetiferous gabbros intruding granites, etc., of the Adirondacks by Gillson and others.[3]

(2) An alternative hypothesis may be mentioned. If these bands are *inclusions* their metamorphism may be ascribed to thermal metamorphism by the enclosing acid gneisses. On this view the coarse hornblende-plagioclase ± quartz aggregates on the face of specimen 4 would then represent a reaction zone between the basic inclusion and the enclosing gneiss, analogous to the hornblende-pegmatites forming a halo to amphibolite inclusions in the Laurentian gneiss of the Haliburton-Bancroft area[4] or in the Lincoln gneisses of Eyre Peninsula, South Australia.[5] In either case the manifold environment of garnet in the rocks under discussion necessitates the incoming of metasomatizing fluids, for it is clear that garnet development cannot be wholly ascribed to chemical reactions within a limited closed system.

---

[1] *19th Ann. Report U.S. Geol. Surv.* 1897–8, Pt 3, p. 400.

[2] (*a*) *Austr. Antarctic Expedition Reports*, Series A, 1918, Vol. III, Pt I, p. 168 *et seq.* (*b*) *Quart. Journ. Geol. Soc. London*, 1921, LXXVII, p. 116. (*c*) *B.A.N.Z.A.R.E. Reports*, 1937, Vol. II, Pt I, p. 13.

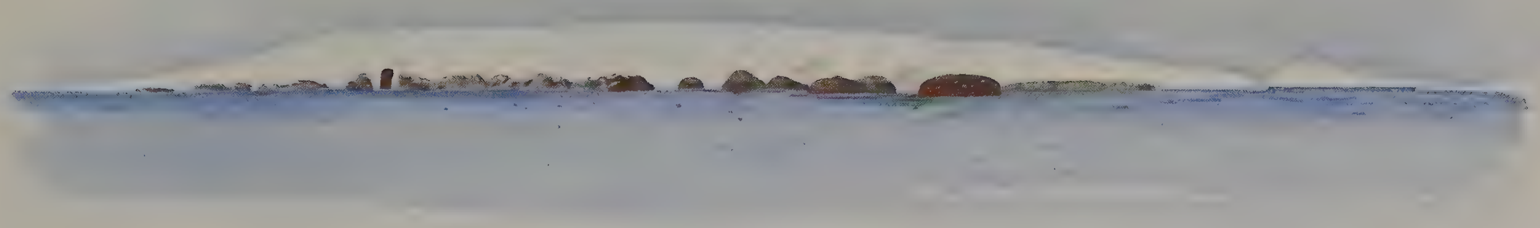
[3] *Journ. Geol.* 1928, XXXVI, p. 149.

[4] *Memoir Geol. Surv. Canada*, 1910, No. 6, p. 76.

[5] *Quart. Journ. Geol. Soc. London*, 1921, LXXVII, p. 83.

PLATE XXXIV

Kemp Land, looking south from about 66° 50′ S, 57° 37′ E. Vertical scale exaggerated.



↑
George Rayner Peak
bearing *ca.* 236°

G.W.R. pinxit

KEMP LAND

PLATE XXXV

Views from Bertha Island.

Fig. 1. Looking northwards from the north-west coast of Bertha Island towards the western part of Islay Island.

Fig. 2. Looking north-eastwards from the north coast of Bertha Island towards the Islay Island and Sheehan Nunatak.

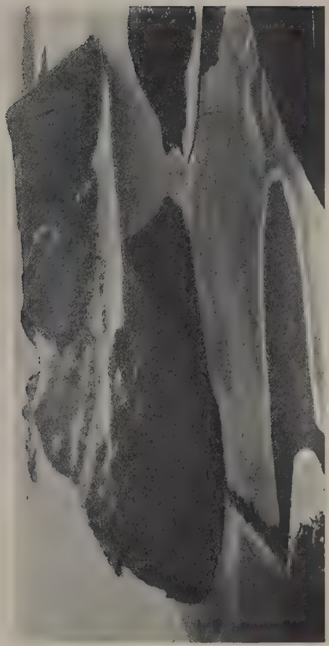
Fig. 3. Looking north-westwards from the north coast of Bertha Island across the mouth of William Scoresby Bay towards Green Point and Cape Wilkins.

Fig. 4. Looking south-south-westwards from the southern slopes of the western end of Bertha Island towards the southern end of William Scoresby Bay.

1

2

3



4

VIEWS FROM BERTHA ISLAND

G. W. Rayner phot.

PLATE XXXVI

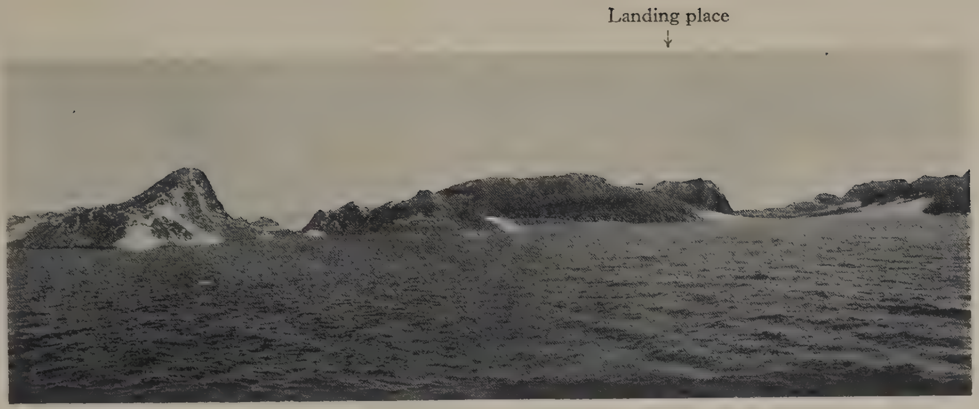
William Scoresby Bay.

Fig. 1. North coast of Bertha Island bearing south from 67° 21′ S, 59° 50′ E, showing landing place.

Fig. 2. Nearer view of north coast of Bertha Island near landing place.

Fig. 3. Sheehan Nunatak bearing north, about one mile, from 67° 21′ S, 59° 56′ E.

Fig. 4. Lealand Bluff, bearing south-west from 67° 24′ S, 59° 40′ E.


Landing place
↓

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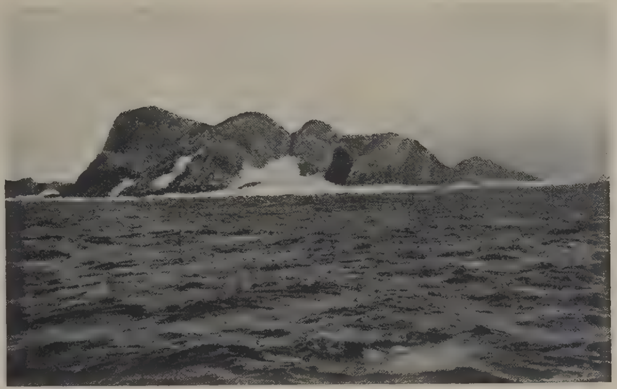


Bernard Dales phot

3

4

SCORESBY BAY

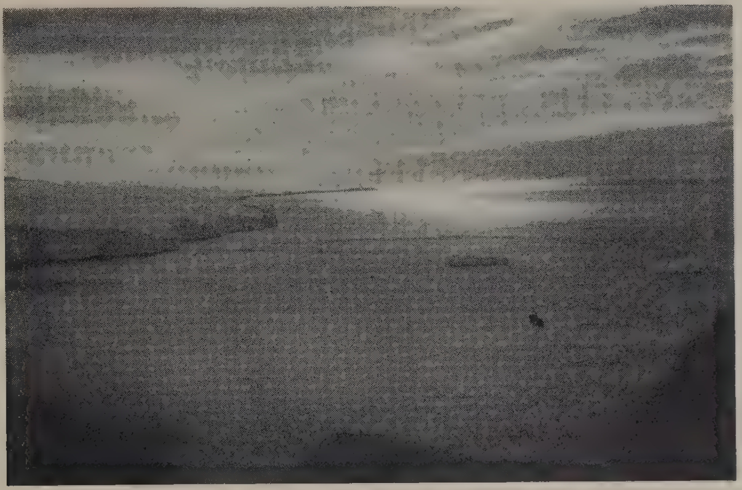
PLATE XXXVII

Scullin Monolith.

Fig. 1. Looking westward from eastern tip of Scullin Monolith.

Fig. 2. Looking eastward from the same point.

Fig. 3. Northern face of Scullin Monolith.



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G. W. Rayner phot.

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SCULLIN MONOLITH

PLATE XXXVIII

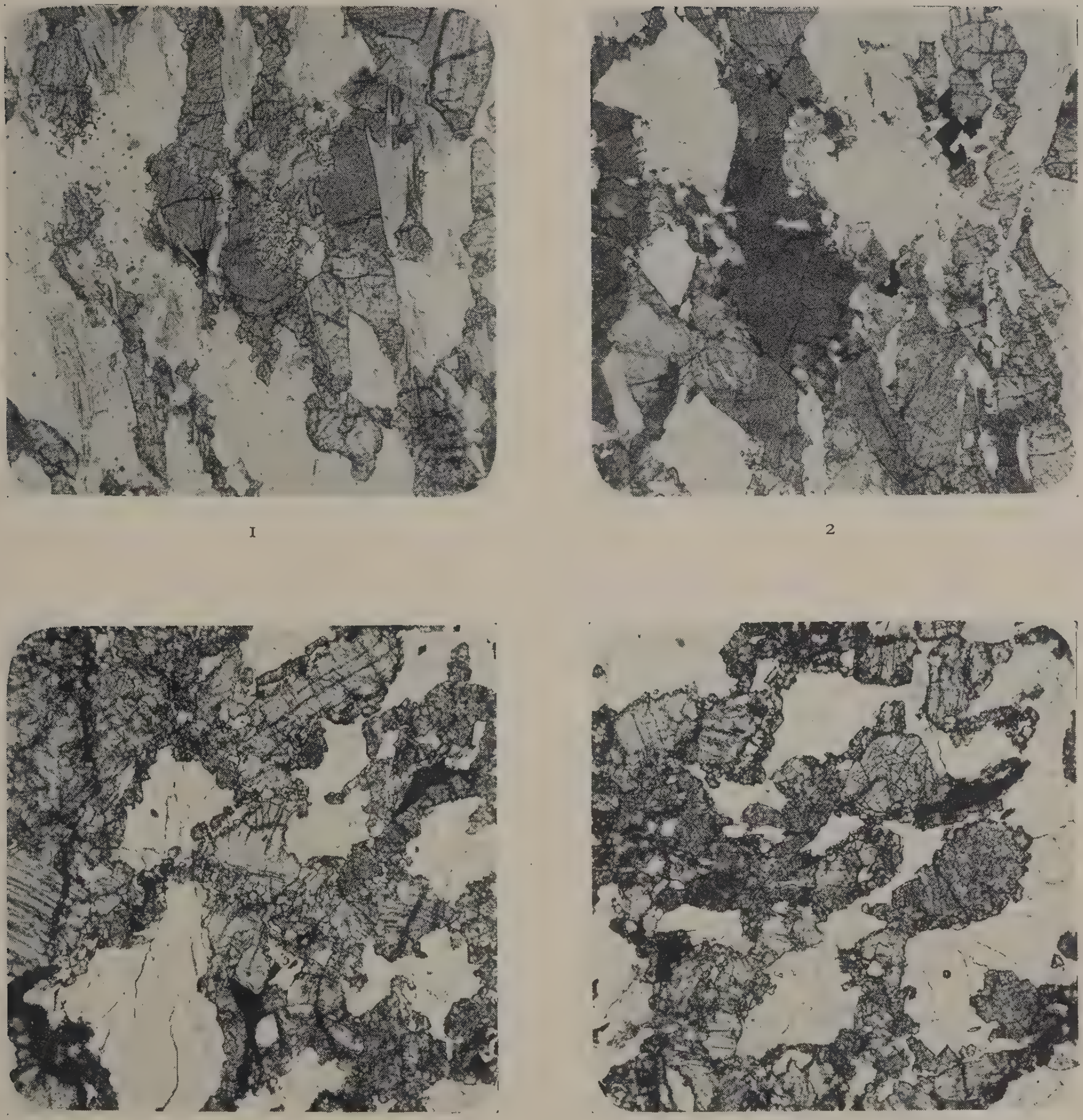
Fig. 1. Metamorphosed Gabbro (foliated), Bertha Island. × 25 diam. Showing augite, hornblende and biotite with a diablastic intergrowth of augite and labradorite embaying a hornblende crystal (centre); felspar in part granulitic. (No. 2.)

Fig. 2. Metamorphosed Gabbro, Bertha Island. × 25 diam. Showing hornblende embayed by an augite-plagioclase diablastic intergrowth. Above right, hypersthene, below left, augite. (No. 4.)

Fig. 3. Metamorphosed Gabbro (garnetiferous), Bertha Island. × 25 diam. Augite (top and centre) with coronae of garnet with intervening ring of quartz. Iron ores in part surrounded by garnet, pyroxene and felspar in part granulitic. (No. 4.)

Fig. 4. Metamorphosed Gabbro (garnetiferous), Bertha Island. × 25 diam. Hypersthene (centre) and augite (top left) with garnet coronae and intervening ring of quartz; a large garnet with fine vermicular augite (right centre). (No. 4.)

Figs. 2, 3 and 4 have been photographed from the one rock specimen and show the change of mineral composition as the contact of coarse hornblende-plagioclase rock is approached. (Cf. text p. 182.)



1 2

3 4

ROCKS FROM BERTHA ISLAND

[*Discovery Reports. Vol. XIX, pp.* 185–244, *Plates XXXIX–XLII, July* 1940]

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INVESTIGATIONS

ON THE ANATOMY OF *GIGANTOCYPRIS MÜLLERI*

By

H. GRAHAM CANNON, Sc.D., F.R.S.
Beyer Professor of Zoology in the Victoria University of Manchester

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ON THE ANATOMY OF *GIGANTOCYPRIS MÜLLERI*

By H. Graham Cannon, Sc.D., F.R.S.
Beyer Professor of Zoology in the Victoria University of Manchester

(Plates XXXIX–XLII; Text-figs 1–17)

INTRODUCTION

The following account of the internal anatomy of the giant deep sea Ostracod *Gigantocypris* was undertaken originally with the intention of discovering what modification in the anatomy of a typical Cypridinid had taken place in the evolution of this relatively enormous form. I took the view that the small Ostracod such as *Doloria*, whose anatomy I had previously described (1931), represented a more primitive constitution from which that of *Gigantocypris* might have evolved and not the reverse—a view put forward by Lüders (1909). I have previously stated my reasons for adopting the view that the primitive crustacean was a minute form (1933) and the same argument will apply to the ancestral Ostracod.

The abundance of material, however, which was placed at my disposal and its excellent state of preservation soon led to a much wider investigation, so that the present paper in addition adds considerably to the description of Cypridinid anatomy which I published for *Doloria*.

Lüders (1909) gave a general account of the anatomy of *Gigantocypris*, and he dealt with certain organs so thoroughly that I have omitted any particular account of them in my own work. Thus the unique nauplius eye, which is a characteristic feature of the genus, I have omitted except for brief references. In addition, as in *Doloria*, I have not dealt with the genital organs or with the labral glands. Lüders has adequately dealt with these systems.

The sections for this work were cut and stained by the head laboratory steward, J. T. Wadsworth, just before he retired after nearly forty years' service to the department. I am grateful of this opportunity of expressing my thanks to him and appreciation of all the useful influence he has exerted over so many zoologists during his long stewardship.

METHODS

Three specimens received from the first commission of R.R.S. 'Discovery' had been fixed in alcoholic Bouin. The smallest of these—about 1 cm. diameter—was cut at 10 μ in ordinary paraffin wax. The body collapsed considerably but was useful for a study of certain organs, e.g. nerve ring and antennal gland. The others were dissected and isolated pieces were embedded. The dissection, however, led to such distortion that they were only of use for minute details, e.g. the constitution of the sphincter of the antennal gland.

The large size of the sections and the length of the ribbons made it clear at once that such a method would add little to the general account of the anatomy given by Lüders (1909). On receiving a second supply of many fine specimens collected by the R.R.S. 'Discovery II', which were fixed in formalin and preserved in alcohol, I decided to try a celloidin method. The impregnation was very lengthy, but it was found in the first few specimens that the thin dorsal dome of the trunk collapsed even though this took several months. This collapse, however, did not interfere with the anterior region and these series were of considerable use. Thus the series of photographs on Plate XL showing the complete nerve ring are from one of these early series. To avoid the distortion I cut away a small window in the shell dorso-laterally and then, through the hole so made, another in the dorsal body wall. This allowed the celloidin to enter the body cavity without any collapse of its walls and resulted in two series of sections in which there appears to be no distortion at all (see Plate XLII).

The celloidin blocks were cleared and cut under cedar-wood oil. This allowed of accurate orientation. The sections were cut very thick, the series ranging from 70 to 120 μ.

The anatomy was worked out by the projection-reconstruction method, and I mention this method particularly as I feel that it is too little used. The image of a section is projected through the microscope on to a sheet of paper. In a thick section it is possible to focus on to the upper surface and then on to the lower. For the first section both these outlines are drawn. The next section is then projected and of course it is found that the upper surface of this section fits accurately on to the outlines of the lower surface of the first section. When the image of this second section has been thus accurately fitted into the drawing of the first section, a drawing is now made of the lower surface of this second section. The succeeding sections are treated similarly, and in this way a series of contours is built up from which the shape of the organism sectioned can be accurately deduced.

It will be obvious that for this method there is an optimum thickness of section. If the sections are too thick there will be too few contours so that an insufficient idea of the solidity will be obtained, whereas if they are too thin inaccuracy is bound to result in superimposing successive outlines, which will differ little from each other. I have stated above the thicknesses which I used for this relatively large crustacean, but the same method can be used for smaller forms, using much thinner sections and greater magnification.

I consider the method very accurate. All the figures in this paper, except where otherwise stated, have been drawn by this method. I found that it was possible to obtain much more accurate representations of the actual limbs from sections than from camera lucida drawings of whole limbs. The view of any such reconstructed limb is naturally determined by the plane of the section, but with three series of sections in planes at right angles to each other three views of the same limb can be obtained which together should represent its whole structure.

An accurate superimposition of the image of one section on the drawings of previous sections is essential for a successful reconstruction. This becomes immediately apparent when following small nerves such as shown in Fig. 14. To obtain this the best method is to use some structures, preferably near the edge of the projected image as guides—structures which maybe will not come into the final picture. Thus, muscles running in various directions can be used. To illustrate this I have photographed (Plate XLII) the series of sections from which Figs. 7*a*, *b* were reconstructed. These figures show the lateral body wall and the underlying pericardial floor. Now these are thin and stain very faintly, and to reconstruct them without the help of some guides would produce a very inaccurate picture. The muscles in the pericardial floor itself were used as such guides, and by comparing the successive sections with Fig. 7 it can be seen how they were used to join the sections together in the projection.

These photographs and Figs. 7*a*, *b* also illustrate how it is possible in this method to omit any structure in the reconstruction and figure only some underlying structure.

Another advantage of the method is that the reconstruction can be carried out in either direction. Thus an outer view of the upper lip and surrounding limbs was obtained for Fig. 3, while by reversing the order of projection an inner view of the same region was obtained for Fig. 8. Actually these are from two separate series.

The sections were stained in Mallory's triple stain or in chlorazol black.

In addition to the sections several specimens were dissected, and for this purpose they were placed under spirit on a piece of black velvet to produce a good background. It was as a result of this method that chlorazol black was accidentally discovered. It is used in the dyeing of velvet, and minute quantities dissolved in the spirit and stained the chitinous sclerites a dark green. A black solution was therefore extracted from the velvet by boiling with spirit, and through the courtesy of Imperial Chemical Industries its main constituent was identified as chlorazol black (Cannon, 1937).

SYSTEMATICS

The genus *Gigantocypris* was established by Müller (1895) to include five specimens of a giant cypridinid collected during the cruise of S.S. 'Albatross', in an open net, off the west coast of Central America, between 100 and 1700 fathoms. These he called *G. agassizii*. In 1920 Skogsberg described a new species from relatively abundant material collected "within the region of the Gulf stream" (p. 218) during the North Atlantic Deep Sea Expedition (1910) of the S.S. 'Michael Sars'. This he named *G. mülleri*. The characters on which Skogsberg bases the distinction between the two forms are:

(1) The length of the shell is greater in *G. agassizii*.

(2) The antennule has seven joints in *G. agassizii* and eight in *G. mülleri*.

(3) The second trunk limb has more than 200 cleaning bristles in *G. agassizii* and up to 140 in *G. mülleri*.

(4) The lengths of the joints and the terminal spine of the endopodites of the antenna.

(5) Short spines are present at the bases of certain of the natatory setae of the exopodite of the antennae in *G. mülleri* but are absent in *G. agassizii*.

The Discovery specimens, as far as they have been examined, all agree with Skogsberg's type, *G. mülleri*. While adopting this specific name, I must emphasize that the differences between Skogsberg's two types are very unsatisfactory. In fact, in only one point is there any certain difference, and the value of this cannot be estimated until the original specimens collected by Müller have been re-examined.

Thus, as regards the length of the shell—14–16 mm. in *Mülleri* and 23 mm. in *Agassizii*—it is obvious that this character alone would be insufficient on which to base a new specific diagnosis.

The last joint of the antennule is very difficult to distinguish. Skogsberg states (1920, p. 204) that it is "often somewhat withdrawn into the seventh joint and rather difficult to verify with certainty". From an examination of the Discovery specimens I can fully support Skogsberg's remarks. In some specimens it is impossible to be certain that the eighth segment is present, while in others it is well marked. It is obvious that in Müller's original specimens the apparent absence of the eighth segment might be due to the small number of specimens, or to the method of preserving them.

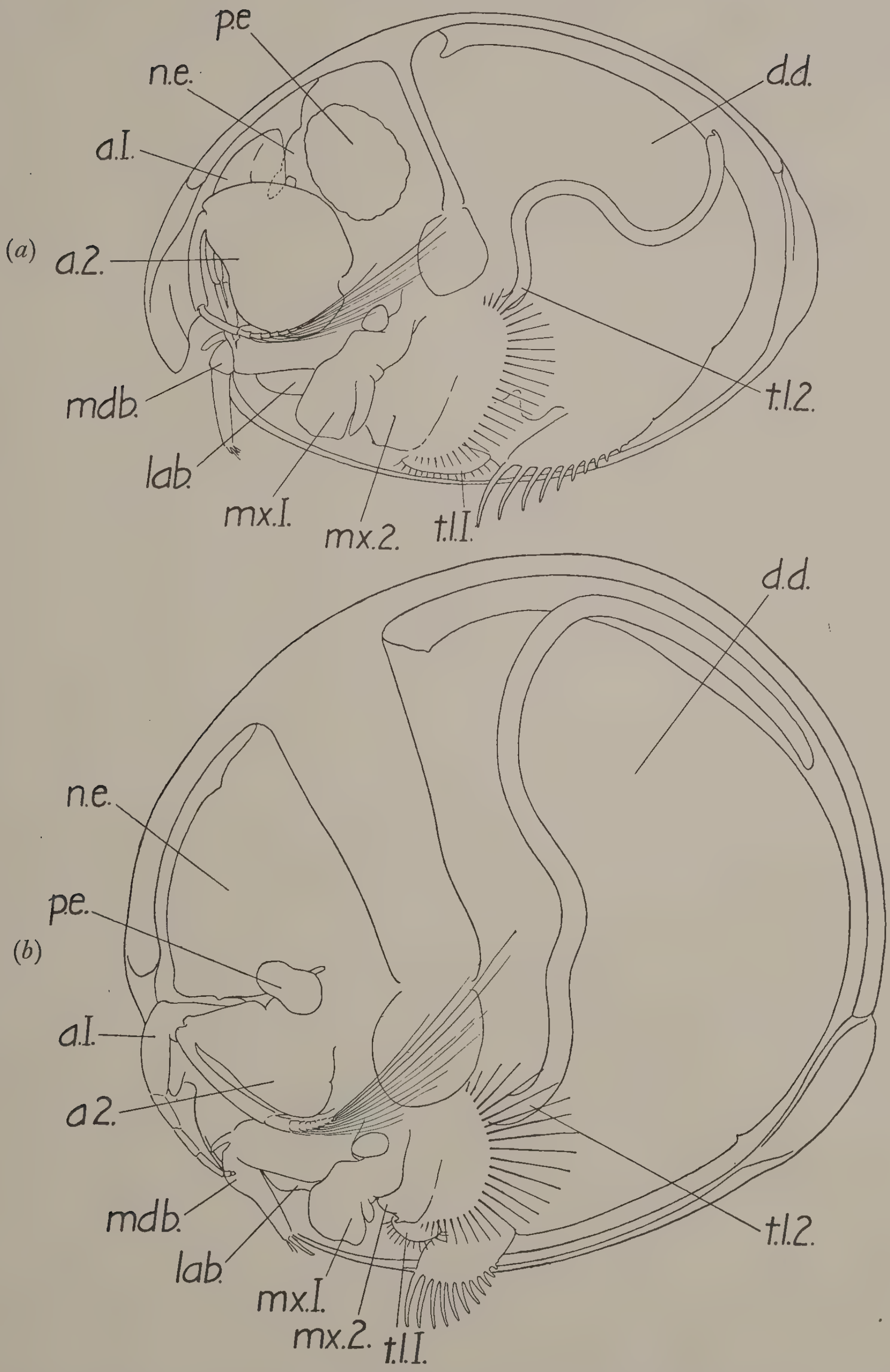
The number of cleaning bristles quoted by Müller is more than 200, and the words he uses, "ich schätze jederseits über 200" (1895, p. 158), indicate clearly that this is only an estimate—no attempt was made at an accurate count. Skogsberg, however (1920, p. 213), states that the number of bristles present is "very difficult to determine with certainty on account of the closeness of the bristles to each other". He has counted the bristles in his specimens and arrives at a figure of not more than 140. This agrees with my count of Discovery specimens, but I can well believe a rough estimate of the number being put as high as 200. The packing of the bristles at their bases gives a false impression of their number.

The length of the joints of the antennal endopodite cannot be relied upon, as Müller gives two figures which do not agree. His smaller figure (Plate III, fig. 1) agrees approximately with Skogsberg's statement, and with a figure by Scott (1911) (Plate II, fig. 6) of a form that Skogsberg claims (p. 217) as *G. mülleri*, while it is upon the larger figure (Plate I, fig. 21) that Skogsberg depends for his measurements of *G. agassizii*.

The last character on which Skogsberg distinguished his new species from the original is the only one which cannot be questioned, except on the suggestion that Müller made an error in his observation. He states definitely, however, "der Dorn, der bei *Cypridina* neben der Basis der Borsten entspringt, fehlt" (1895, p. 158). In Skogberg's material, and in those Discovery specimens which I have examined, stout spines are present at the bases of the natatory setae of the antennal exopodite.

GENERAL COMPARISON WITH A TYPICAL CYPRIDINID

The Ostracodan carapace has the form of a bivalve shell, and in all Ostracods except *Gigantocypris* the two valves of the shell can be opened in the same way as those of a bivalve mollusc. To enable this to take place the two valves are joined together dorsally along a certain length to form a hinge. This hinge is relatively short in those cases, such as Cyprids, where the outline of the valves, as seen from the side, is elliptical.


p.e
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d.d.
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p.e.
(b)
a.I.
a2.
mdb.
t.l.2.
lab.
mx.I.
mx.2.
t.l.I.

Fig. 1. Outline sketches of *Doloria* (*a*) and *Gigantocypris* (*b*) after removal of left valve, for comparison. *a*.1, antennule; *a*.2, antenna; *d.d.* dorsal dome of trunk region; *lab.* labrum; *mdb.* mandible; *mx*.1, maxillule; *mx*.2, maxilla; *n.e.* nauplius eye; *p.e.* paired eye; *t.l.*1, first trunk limb; *t.l.*2, second trunk limb.

It is obvious that this must be so, for if a hinge is functional its axle must be straight, or approximately so, and only a short piece of the oval outline of a Cyprid can be considered as approximately straight. If the fusion between the two valves is relatively great, as in the Halocyprids, then it is found that the dorsal side has become flattened out to produce a long straight axis for the hinge. In *Gigantocypris*, however, there is no such dorsal flattening—the outline, when seen from the side, being in fact almost circular—and yet the fusion between the two valves extends more than half-way round the circumference (Fig. 1). This is the character which was used by Müller (1912, p. 9) for distinguishing *Gigantocypris* from all other members of the subfamily Cypridininae, to which it belongs, and it might equally well have been used to distinguish it from all other Ostracods. The fusion between the two valves is complete and is marked by a definite line (Plate XXXIX, figs. 9, 11), but this represents merely a slight thickening of the chitin and no line of flexure.

It may thus be stated that the body of *Gigantocypris* is enclosed in an almost spherical shell provided with a ventral slit, which represents the relatively short length over which the valves are not fused. The slit is enlarged at both ends, anteriorly as the "rostral incisur" (Plate XXXIX, figs. 6–8) and posteriorly as an oval opening (Plate XXXIX, figs. 9–11) which Müller states (1895, p. 156) is absent in other Cypridinids. In between, the edges of the valves are close together, and there is no evidence that the narrow slit between them can be widened in any way. From the antennal notches, which together form the "rostral incisur", back as far as the base of the caudal furca, the edges of the valves are wedge-shaped and merely come together closely, but behind this region and back to the posterior oval opening they are asymmetrical and in section appear to fit into each other, thus producing a very effective closure.

The anterior enlargement of the ventral slit consists of a median prolongation forwards (Plate XXXIX, fig. 6) from the two lateral antennal notches. This median part is never really closed, but its margins are heavily armed with setules. It always forms a narrow space through which the antennules can be projected (Plate XXXIX, fig. 7). The antennal notches, as in the majority of the Myodocopa, serve as rowlocks for the swimming organs, the exopodites of the antennae (Plate XXXIX, fig. 3). The long basal joint of the exopodite presses close against the base of the emargination (Plate XXXIX, fig. 8), and, as this joint is relatively slender, it does not completely fill the antennal notch. Consequently, where the mouths of these notches meet, there is a small median opening. This is the only effective entrance into the cavity of the spherical shell. It is through this aperture that all food and water for respiration must be taken in.

For the further comparison of the body and limbs of *Gigantocypris* with those of a typical Cypridinid the important point to be grasped is that, while the carapace has enlarged to such a great extent, the limbs have neither enlarged proportionately, nor have they become spaced out (Fig. 1 *a*, *b*). They remain closely packed together, having the same interrelations as in *Doloria* and occupy only a relatively small antero-ventral region of the whole organism. As a result, the region posterior to the limbs has become an enormous hemisphere (Plate XXXIX, fig. 1), while the region in front, that is, between the attachment of the foremost limbs at the top of the labrum and the heart, has become spread out, and it is this region which shows the most important structural peculiarity of *Gigantocypris*.

In *Doloria* this space is occupied by a normal-sized nauplius eye, from the middle of which projects a finger-like frontal organ (dotted in Fig. 1*a*, and Cannon, 1931, text-fig. 2). Abutting on either side are the normal-sized paired eyes. These, in side view, appear to occupy a triangle bounded posteriorly by the attachment of body to shell, anteriorly by the shell itself, and ventrally by the antennae. In *Gigantocypris* this triangle is very large, but instead of the paired eyes enlarging to occupy it these have dwindled to vestigial sacs, while it is the nauplius eye which has enlarged.

This extraordinary organ was erroneously called the frontal organ by Müller (1895, p. 159), a mistake that was corrected by Lüders (1909, p. 119), who gives a fairly complete description of the organ. Neither worker identified the true frontal organ. This I have identified from its nerve supply as a minute tubercle situated on the lower median edge of the nauplius eye, about half-way between the tip and the upper limit of the labrum (Figs. 1*b*, 12, and Plate XLI, figs. 1, 3).

The shape of the nauplius eye has never been accurately figured. Müller (1895, p. 159) refers to it as "nasenförmiger Körper", and it certainly can be compared with the human nose. The median ventral ridge, which bears the minute frontal organ, can be compared with membranous septum or *columna nasi*. The *alae* or membranous outer walls of the nostrils are represented by lateral spherical bulges just above the paired eyes which extend forwards to the narrower median ridge of the nose. I have attempted to show this shape in Fig. 7*a*, and it can be seen very faintly in Plate XXXIX, fig. 1. Usually in preserved specimens the extremely thin membrane which covers the eye has collapsed, but in the specimen photographed and in a celloidin series of sections it remained undisturbed.

SWIMMING AND FEEDING

From its shape and actual size it may be safely deduced that *Gigantocypris* is unable to move quickly through the water. It is not accurately spherical as it is slightly "stream-lined", but even so, its enormous size—the size of a cherry—makes it impossible for it to move under its own power with any speed. Specimens collected on the expedition have frequently arrived living at the surface, and Dr Kemp has had several opportunities of observing them alive. In a letter he states: "...we have had them in bowls of sea-water on various occasions, and I am sure that they are not capable of any rapid movements—as indeed one would guess from their shape. They rock and roll a lot, finding it difficult to keep on an even keel, and swim feebly...." Despite this they feed on most active prey. One specimen contained the remains of two giant *Sagitta*, while it held a third in its mandibles, and another contained the telson and two somites of a Brachyuran zoaea. Dr Seymour Sewell kindly examined slides of the gut contents of a third specimen and among the Copepods found two "...examples of *Pleuromamma robusta* Dahl, male; in addition to these two specimens there were the remains of five other examples of *Pleuromamma* sp.,...in addition there were three examples of *Heterorhabdus* belonging to two different species". Still another specimen contained the half-digested remains of a small fish, among which the fin rays and notochord were easily identifiable. These specimens—*Sagitta*, free-swimming copepods, young fish—are all active animals, and yet *Gigantocypris* can and does catch them. This is especially remarkable in the case of the Copepods, for these have a very rapid escape reaction—at any disturbance they dart away at an extremely high speed.

There are thus two facts to be reconciled, first, that *Gigantocypris* is sluggish in its habits and incapable of rapid movement, and second, it feeds on most active prey. I can only suggest that it is on the whole a sedentary feeder, waiting for food to come to it and catching it as it passes by, more in the manner of a sessile animal. But this involves very active mouthparts for, as I have already explained, the valves of the shell cannot be opened, and the only passage to the mouth is through the small opening at the confluence of the antennal notches. If a particle drifts by this opening, or if live prey swims by, it can be grasped in the usual Cypridinid manner by the mandibular palps on either side of the mouth. But the mouth and the mandibular palps may be well inside the shell, and hence there must be a mechanism whereby the mouthparts can be pressed downwards on to the antennal notches so that the mandibular palps can be thrust out. This is made possible, I believe, by the peculiar criss-cross musculature of the dorsal body wall of the trunk region. In *Doloria* I suggested (1931, p. 448) that the "...function of moving the body fluids...must be the main function of the dorsal body wall...". In *Gigantocypris* I have been able to substantiate this point much more fully and consider that this movement of body fluid leads to a movement of whole parts of the body, and that it is by this means that the mouth region is brought up against the ventral slit during feeding.

Before discussing in detail the skeletal adjustments controlled by this hydrostatic system there is a view, in my opinion erroneous, of the constitution of the main body of *Gigantocypris* which must be mentioned. The space inside the hollow spherical shell is almost filled by the body of the *Gigantocypris* (Fig. 1; Plate XXXIX, fig. 1). The greater part of this body—the posterior part—is itself spherical and concentric with the shell. Now Müller (1895, p. 156) and Lüders (1909, p. 105) both maintained emphatically that this distended body is a sac full of blood, or at least contained a marked preponderance of blood over the other tissues. This is, I think, the general opinion concerning those planktonic forms which have adopted a spherical shape, or, in comparison with their near relatives, are in a distended condition, such forms as *Mimonectes* and *Nebaliopsis*. In *Gigantocypris*, however, this is not so. The posterior part of the body contains a large gut, always laterally compressed, even when distended with food remains. Between this gut and the dorsal and lateral body walls there is a large mass of gut parenchyma, arranged in the typical Cypridinid manner, that is, as a thick layer completely covering the gut and stretching to the dorsal and lateral body walls as several longitudinal ridges. In between these ridges there is fluid—blood—but, by comparison with sections of other Cypridinids, it is clear that this is not present in any excessive amount. In *Doloria* I have preparations in which there is certainly more fluid in the trunk than in any of my *Gigantocypris* preparations. On the other hand, I have sections in which the whole trunk region appears to be full of gut parenchyma. I remarked on the variation of this tissue in *Doloria* (1931, p. 462) and suggested that it was probably correlated with food storage. I think now that this variation is more apparent than real. What varies is not so much the parenchyma as the blood. If there is a lot of blood then this gives the appearance of a relatively small amount of gut parenchyma and of a distended body.

A large amount of blood in the trunk will occur when the body is drawn well into the shell. If, now, the circular and dorsal longitudinal muscles contract, then since they together form a dome-shaped cover to the trunk region, they must press on the body fluid. Since the blood is incompressible it must, as a result of this pressure, move out of the trunk into the anterior part of the body. This will push down the mouth region and associated mouthparts towards the ventral slit through which the mandibular palps can now be thrust. Now the mouthparts, as I describe in detail later, are rigidly connected to the adductor tendon. When the dorsal body wall contracts this whole ventral mass moves downwards, and, as a result, the adductor muscle and its median tendon must become bowed. Attached to the median tendon there are two muscles, the dorso-ventral body retractors (Plate XXXIX, fig. 2). These commence near the middle point, each as a thin tendon which then runs as a double muscle to attach to the outer layer of the valves (Fig. 8) just posterior to the attachment of body to shell. The muscles sometimes bifurcate so as to give a quadruple attachment to the shell (Fig. 5, muscle 10, and Fig. 7*a*). These muscles are the antagonistic muscles to the dorsal body wall. When they contract they must tend to pull the ventral body mass upwards into the cavity of the shell. The whole part of the body, ventral to the adductor muscle, can thus be looked upon as a system the movement of which is hydrostatically controlled by the co-ordinated activity of the muscular dorsal body wall together with the dorso-ventral body retractor muscles.

CONSTITUTION AND ORIGIN OF DORSAL BODY WALL

The constitution of the dorsal body wall has been described briefly for *Doloria* (Cannon, 1931, p. 446). In *Gigantocypris* I have been able to make out its structure in much greater detail. The outer layer consists of a thin ectoderm, consisting of an epithelium of flattened polygonal cells containing nuclei which are so flat that they do not protrude from the surface. Inside this, and attached at short intervals to the ectoderm, are the circular muscles, commencing from near the mid-dorsal line and running on either side to the mid-lateral part of the body. Inside this again, and attached both to the circular muscles and through them to the ectoderm, are the dorsal longitudinal muscles, running from the sclerite of the caudal furca to the frontal region, that is, at right angles to the circular muscles. Finally, attached to the dorsal longitudinal muscles, and in their plane, is a thin sheet, the posterior pericardial floor.

The ectoderm is covered on the outside by a thin layer of cuticle. It is difficult to see this in section as it rarely lifts away from the ectoderm cells. Its presence, however, can be demonstrated by staining with chlorazol black, and this stain shows, further, that the cuticle varies in thickness, being thicker towards the posterior margin bordering the caudal furca. In the thinner anterior part it stains a purplish grey, while posteriorly it takes on a definite greenish tint like the sclerites.

The structure of the ectoderm itself can be seen through the musculature in preparations of parts of the body wall stripped off and mounted flat, but in one fortunate specimen I found it possible to dissect off the ectoderm alone without disturbing the underlying musculature. It showed the typical appearance of pavement epithelium, with extremely flat nuclei, but also at one point, a peculiarity to which I refer later in connexion with the probable origin of the circular muscles.

The arrangement of the circular muscles is such that they radiate approximately from the attachment of the adductor muscles (Fig. 9). They appear to emerge gradually from the lateral ectoderm and disappear similarly into the dorsal ectoderm on either side of the middle line. At their dorsal ends they show typical structure, but ventrolaterally Krause's membrane disappears, and more lateral still the myofibrils become continuous. At their ectodermal attachments the fibrils appear to spread out into the ectoderm cells as if the muscle were frayed.

The relation of the circular muscles to the other components of the body wall can be made out very clearly from the thick celloidin sections of adult specimens, but even better in a thin section of an advanced embryo.[1] Here the circular muscle appears to lie along the summits of rows of pyramidal ectodermal cells whose tops project inwards (Figs. 2*a*, *b*). In fact, from the position of the nuclei, the ectoderm cells must be arranged in this young stage in rows corresponding to the circular muscles. This linear arrangement is lost in the adult and the nuclei become flattened out so as to be difficult to see in a section of the ectoderm, but the connexions to the circular muscles remain as fan-shaped bundles of fibres. The two figures (Figs. 2*a*, *c*) illustrating this point are parasagittal sections which naturally cut across the circular muscles.

In a transverse series, that is, one which includes a section in the plane of the adductor muscle, it is always possible to find a section which includes the whole of a circular muscle. Fig. 2*b* shows such a section. Here the muscle can be seen lying close against the inner face of the ectoderm cells and then extending gradually at either end into a group of ectoderm cells which are stretching out towards it. The fibres upon which the cross-striations will subsequently develop run as a distinct band up to the point approximately where the muscle branches out into terminal connexions, but there does not appear to be any definite boundary between the two zones.

In the adult the termination of the muscle by its merging into the ectoderm is even more marked. The striations cease near the converging ectoderm cells, but fibrillae extend into these cells to the cuticle itself. These can best be seen in a preparation of the body wall mounted flat. The individual fibres stain intensely in chlorazol black and

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[1] *Gigantocypris* carries its eggs inside its shell (Plate XXXIX, fig. 10). It is peculiar in that the eggs do not hatch as a nauplius but as a young adult.

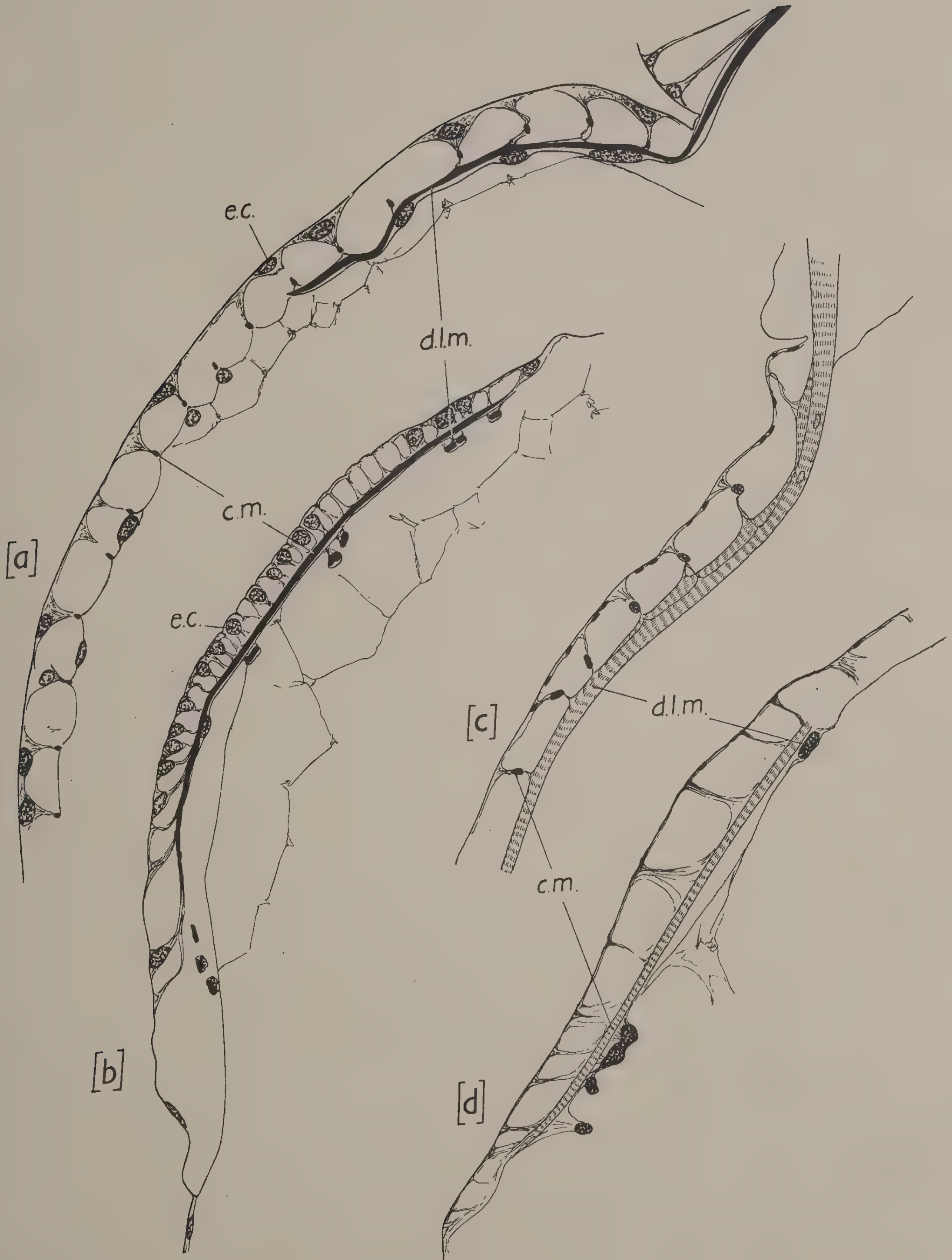

Fig. 2. Parasaggital section (*a*) and transverse section (*b*) of *Gigantocypris* embryo to show origin of circular muscle from dorso-lateral trunk ectoderm (×195). Corresponding sections (*c*) and (*d*) of adult for comparison (×65). *c.m.* circular muscle; *d.l.m.* dorsal longitudinal muscle; *e.c.* ectoderm cells.

can be traced extending spread out irregularly for some long distance beyond the apparent end of the muscle.

Before discussing the origin of these circular muscles the dorsal longitudinal system may be dealt with briefly. These muscles lie in the pericardial floor which rests against the inner face of the circular muscles (Fig. 2*d*) in the same way as the latter are attached to the cuticle through the ectoderm cells. Their number and disposition is dealt with more fully in the section dealing with the blood system.

I discussed the origin of the circular muscular system in Ostracods in my paper on *Doloria* and suggested that these muscles are of the type whose development I had studied in other forms such as *Chirocephalus* and *Cypris* and had found to be ectodermal. This view has been criticized by Goodrich, one of whose pupils (Needham, 1937, p. 559) has recently attacked my results and those of Dr Manton who likewise found ectodermal muscles in her work on *Hemimysis*. Needham's observations were based on material (*Neomysis*) collected by Professor Goodrich and preserved in Bouin. Now Bouin is a notoriously poor fixative for crustacean embryos, and for this reason it would be unwise to put Needham's figures against the beautiful preparations figured by Miss Manton. It must be remembered that Dr Manton only undertook the embryology of *Hemimysis* after I had found that B. G. Smith's fixative gave results as near perfect as could be. However, apart from this bad technical fault, Needham argues in favour of his view that among those who suggest that ectodermal muscles may occur "...there is not good agreement in the evidence from different forms" (p. 503), and even publishes a table to show how Miss Manton's results disagree with my own. Actually, we do not expect agreement. The fact that the extensor muscles of the limbs are ectodermal in *Hemimysis* according to Dr Manton, and mesodermal in *Chirocephalus* according to me, does not mean that one of us must be wrong. In the table Needham publishes he records my observation that the sphincter muscle of the maxillary gland of *Cypris* is ectodermal while it is mesodermal in *Chirocephalus*. Does he imply, from his table, that I must be wrong in one of these cases? I can see no other reason for publishing it.

Needham has evidently not seen my views, with which I think Dr Manton would agree, which I published in my report on *Doloria*. Here I stated (1931, p. 448) that "...the Crustacean ectoderm is...a supporting tissue of varied potentialities. It may produce a hard external plate or sclerite. It may pass inwards and produce an endoskeletal apodeme...", and so on. *It has these potentialities*—that is all I maintain. But the fact that it gives rise to muscles in a certain region in one form does not imply that it does so in the same position in all forms.

The work on *Gigantocypris* has added to my observations on *Doloria* and has strengthened my view that the whole of this circular system of muscles is actually derived from the ectoderm. First, I have been able to study an embryo where the limits of the ectoderm cells are very clear, and the discovery of chlorazol black has enabled me to study the distribution of the terminal fibrillae of the muscles.

The embryo, as I have pointed out above, shows that at an early stage the muscle cells are continuous with the ectoderm cells. Then in the adult the striations which are quite distinct at the upper end of the muscles disappear towards the lower ends so that the myofibrils form a continuous bundle. Now these gradually spread out and run through the substance of several ectoderm cells before reaching the cuticle. All these morphological points suggest a persistent continuity between the muscle and the ectoderm cells and are in agreement with the idea of the muscle itself being ectodermal.

However, my strongest point in support of this view, I consider, comes from a consideration of the possible evolution of these muscles. We know, from the recent study of crustacean embryology, that the fate of the coelomic sacs is constant throughout the group. Dorsally they creep up on either side of the gut to form the heart and then, after giving off the dorsal longitudinal muscles, they collapse to form the pericardial floor. Ventrally they give rise to a mass of mesoderm from which develops the ventral longitudinal series and sundry other muscles which may run in any direction and may be associated with movements of limbs on the segments. The dorsal and ventral longitudinal series are concerned only with extension and flexure of the body as a whole. Moreover, the dorsal longitudinal series *are the only muscles above the pericardial floor*. In the development of these muscles the cells forming the upper and outer wall of the sac multiply and arrange themselves longitudinally. In this way one continuous longitudinal muscle is formed. This may subsequently elaborate so that parts of it become twisted in relation to other parts as, for instance, in the trunk musculature of a Decapod. But always, whether the musculature is twisted or not, it runs from one segment to the segment behind. Now in *Gigantocypris* we have just the reverse. The circular muscles, even in their embryonic stages, run in a plane transverse to the body. There is never any obliquity or, during development, any twisting round of originally longitudinally placed muscle cells. If now the circular muscles are mesodermal they must have evolved from the longitudinal series, for as I have emphasized this series is the only series above the pericardial floor and is present throughout the Crustacea, or even Arthropoda. This being so, there must have been stages leading up to these present conditions where the mesoderm cells swing round from their original longitudinal position to their present transverse position. Now, as I have just pointed out, there is no trace during development of a rotation of mesoderm muscle cells, but more particularly it is difficult to see what advantage the initial stages in such an evolutionary step would have been.

In considering my suggestion that the circular muscles are derived directly from the ectoderm it must be remembered that the fact that the dorsal body wall of the trunk region is soft and flexible is just as characteristic of the Ostracods as is the possession of a bivalve shell. The two characters are probably correlated and evolved together from an ancestral form in which the tergal exoskeleton of the trunk region was rigid in the typical crustacean manner. But it was to this dorsal skeleton that the segments of the dorsal longitudinal muscle were attached. Now as the dorsal chitin gradually softened this would cause the support for these attachments to disappear. A muscle cannot work unless it has something rigid to pull against, and hence it can be deduced that as the rigid dorsal chitin softened a compensation must have developed to take its place.

This, I maintain, was produced by an internal body pressure tending to inflate and so put in a state of tension this softening dorsal body wall. A tense body wall is rigid and hence would provide points of attachment for the dorsal longitudinal muscle. Now tissues that are stretched often develop fibres, and I have shown in a series of forms all gradations between the appearance of simple fibres leading to typical striped muscle. This is what I consider has taken place in the Ostracodan body wall. The body pressure led to a state of tension in the ectoderm and this led to the development of fibres which eventually evolved into striated muscle. The way in which I consider that these ectoderm cells, in which the myofibrils developed, sank in and became internal muscles is illustrated at one point on the preparation of isolated ectoderm to which I have already referred (p. 196). Here two ectoderm cells, which are *not* adjacent, are seen to be connected together internally. That is, on the inner face of the ectoderm there is a bridge spanning a gap about two or three cells wide and joining two ordinary ectoderm cells otherwise completely separated. I suggest that the two cells at the ends of the bridge are sister cells and that the connexion between them has failed to break down. If, now, myofibrils were to appear in this bridge we should be well on the way towards an internal muscle derived from ectoderm, and we should have a structure comparable with the muscular sphincter of the maxillary glands of a Cyprid whose development I have previously worked out (Cannon, 1925).

The meaning of the arrangement of the circular muscles across the dorsal longitudinal series I think can be understood by considering what would happen if they were absent and the dorsal longitudinal muscles contracted alone. The pressure produced by the latter muscles would cause the lateral parts of the body wall to bulge outwards. The system of circular muscles radiating from this lateral region naturally counteracts this tendency and so allows the contraction of the body wall as the means of controlling the movement of fluid in the body.

One further point may be mentioned here. In the case of *Doloria* I pointed out (1931, p. 447) that the dorsal body wall in its constitution is Annelidan. That is correct morphologically, but only partly so physiologically. Both the Annelid body wall and the Ostracodan trunk wall function in putting up and controlling the internal body pressure, but whereas in the former the longitudinal muscles and the circular muscles are antagonistic, in the Ostracod they work together.

ENDOSKELETON AND ARTICULATED SCLERITE SYSTEM

A potash preparation of *Gigantocypris* appears to consist of three distinct skeletal systems—the shell, a ventral framework supporting the limbs, and the caudal furca, all three held together by the flimsiest of cuticles. The skeletal elements within each system can be studied in such a preparation by the acid fuchsin method, but by the use of chlorazol black it was possible to stain the sclerites in whole preparations without previous maceration in potash. The muscles stained a brownish red, while the skeletal elements stained a distinct greenish grey. The extremely thin cuticle stained the palest grey of an indigo shade from which the greenish tinge was absent.

The ventral framework to which all the limbs are articulated is built up on a chitinous plate situated immediately behind the mouth, the extent of which can be seen clearly in the semi-diagrammatic view of the ventral skin of *Doloria levis* (Cannon, 1931, p. 443, fig. 3). It is a quadrangular plate. Its front edge is the hind wall of the mouth (Plate XL, figs. 2, 8). Its hinder margin is formed by the two first trunk limbs which come close together in the middle line. Laterally, in emarginations on either side, are the three limbs, mandibles, maxillules and maxillae. The plate itself is not very substantial—it is its margins that are thick and stain deeply. It extends forwards round the sides of the mouth and continues as a deep band, the upper labral loop, around the upper half of the labrum and bears at its middle point a frontal knob (Fig. 4). This is a useful landmark in comparing the nauplius eye regions of *Gigantocypris* and *Doloria*. From the sides of the mouth there articulates ventrally the helmet-shaped armature of the lower part of the labrum. This lower armature is supported at its upper margin by a powerful sclerite system in the form of a complex loop, which I described in *Doloria* as the equatorial loop. Between this loop and the frontal knob is thin flexible cuticle (Figs. 3–5). This and the articulation at the sides of the mouth permit of the labrum being raised and enlarging the mouth entrance. The muscles effecting this can be seen in the photograph (Plate XLI, fig. 3).

From the sides of the upper labral loop extend inwards the large antenno-labral apodemes, typical hollow chitinous intuckings.[1] The entrance to the apodeme on the animal's left side can be seen clearly in Fig. 3 between the cut-off antenna and the labrum. These apodemes pass inwards in a postero-median direction (Fig. 6) and attach to the tendon of the adductor muscle. Similarly, from the sides of the mouth a pair of more powerful apodemes extend directly inwards to attach to the same tendon just median to the attachment of the antenno-labral apodemes. These are the anterior hypostomal apodemes (Fig. 6). The ventral framework with its articulated limbs is thus most rigidly connected through this double apodemal system to the adductor tendon, and, furthermore, there is no similar connexion to the valves. The body thus "floats" inside the spherical shell, being held in position by the adductor muscle, and this, I consider, is the main function of the muscle in this genus. As I have already pointed out (p. 192), the valves have fused together to such an extent that it does not appear possible that the ventral unfused margins can be opened and closed. Hence the adductor muscle cannot carry out its normal function, and yet it persists as a comparatively massive muscle. This is understandable if its suspensory function is considered now as its main function. I do not consider that this is a new function that developed with the evolution of the genus, but rather that in all other Ostracods the adductor muscle has a double function. It has its normal function of closing the two valves, and, in addition, has the suspensory function that I describe here.

Another connexion of the body framework to the valves does exist through the articulated sclerite system, but this is only rigid in so far as its musculature makes it so.

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[1] The hollow nature of these apodemes was made very evident in one series in which the antenno-labral apodeme contained a large number of fragments of radiolarian skeletons.

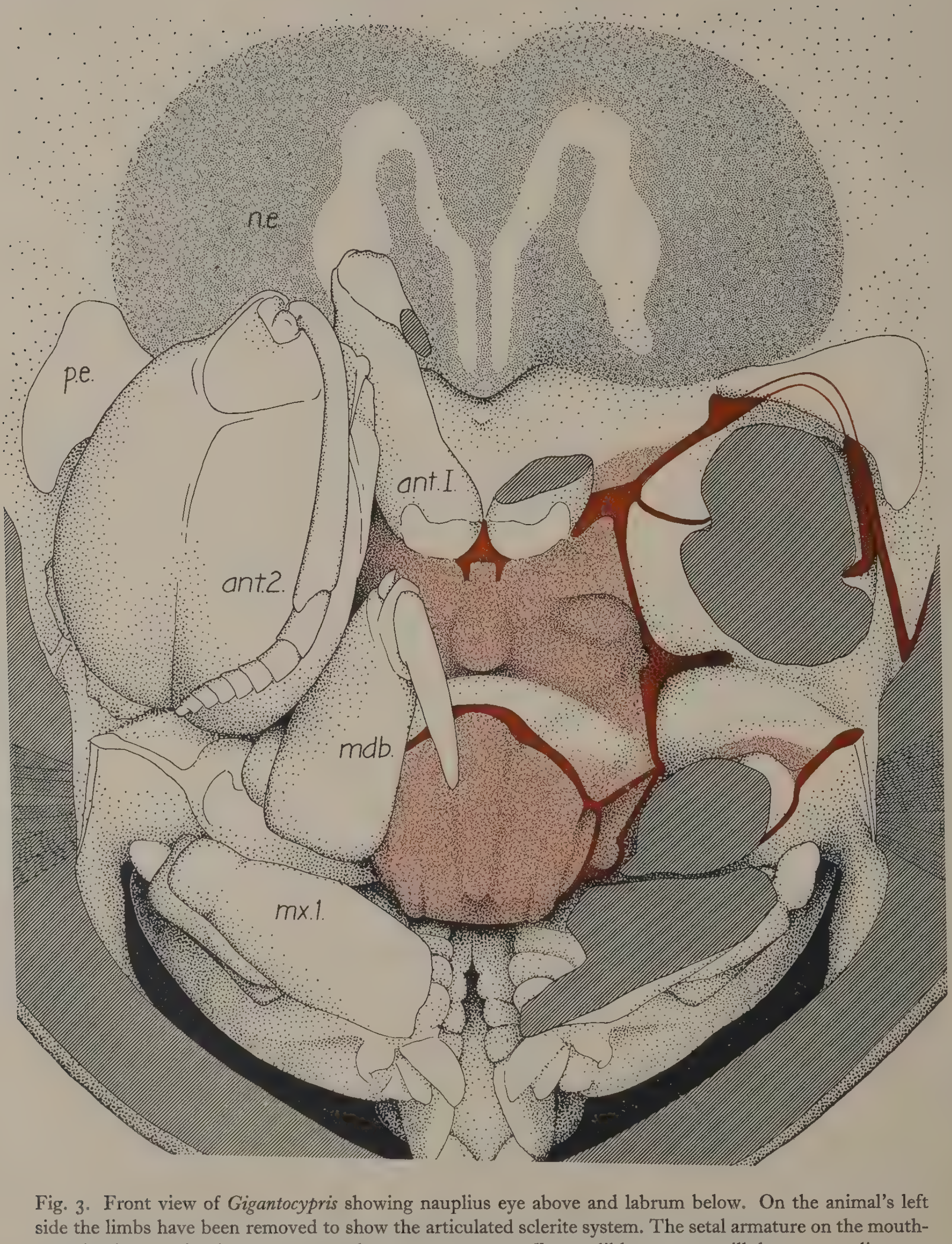


Fig. 3. Front view of *Gigantocypris* showing nauplius eye above and labrum below. On the animal's left side the limbs have been removed to show the articulated sclerite system. The setal armature on the mouthparts has been omitted. *ant.*1, antennule; *ant.*2, antenna; *mdb.* mandible; *mx.*1, maxillule; *n.e.* nauplius eye; *p.e.* paired eye.

It is through this system that the limbs are moved relative to the ventral framework. I described this briefly in *Doloria levis* (1931, p. 441), but in *Gigantocypris*, by using chlorazol black, I have been able to study the associated musculature and have deduced the manner in which this sclerite system functions. The central point of the system is a structure that I call the lateral brace, the position of which can be understood only in relation to the attachment of body to valves. This attachment is naturally bounded by a margin where the ectoderm of the body is reflected on itself and continues as the inner lining of the valves. It extends downwards from the dorsal region of the heart as an isthmus, and just below the equatorial region enlarges as a circular peninsula which surrounds the attachment of the adductor muscle (Figs. 4, 5). The two margins, anterior and posterior, of the isthmus are connected together throughout their length by a sheet of attenuated cells, probably of ectodermal origin (Plate XLII, figs. 5–9). But at the lower end of the isthmus there is a powerful strut, the lateral brace, which connects the two margins (Figs. 4, 5 and Plate XLII, figs. 5, 6). I have not called this a tendon because it does not serve as the attachment of a muscle to a skeletal part. On the other hand, it is not entirely apodemal. The hinder three-quarters is a true ectodermal intucking, that is, an apodeme, and this persists like the rest of the exoskeleton after treatment with potash (Fig. 4). The anterior quarter, however, while not being muscular, yet dissolves in potash (Fig. 5); it is endosternal in nature, like the adductor tendon, and not endophragmal like the true apodemes. Despite this double nature it functions as a single inextensible brace, and from its position it will be seen that it occupies a key position rigidly connecting the anterior and posterior parts of the body.

From its anterior end there extends upwards a thin skeletal rod, which is the hinder member of a tripod (Figs. 3–5). This corresponds to the sclerite which I have called *a* in *Doloria*. From near its upper end the outer member of the tripod articulates as sclerite *d*, extending downward behind and to the outer side of the massive basal joint of the antenna (Figs. 3, 4). It then continues upwards for a certain distance to the apex of the tripod, which is situated just behind the stalk of the rudimentary paired eye (Fig. 3), and then sharply downwards again. In *Doloria* I distinguished two separate sclerites here, the upward extension *b* and the downward branch *c*. In *Gigantocypris* I cannot find any separation, either between these or between *b* and *a*. Hence, I am referring to this inverted V-shaped sclerite as *abc*, and the single letters refer to the separate regions I have described.

The lower end of *c* divides into three unequal sclerites. A very thin outer branch runs laterally to support the inner side of the attachment of the antenna to the body (Fig. 3). A middle branch runs downwards and is continuous with the median side of the intucking which becomes the antenno-labral apodeme (Fig. 3). An inner massive branch runs to the articulation of the antennules to the body, and as these articulate close together in the middle line in an area of relatively rigid chitin, these inner branches of *c* sclerite are, in effect, joined rigidly together (Fig. 3).

The ventral framework is thus connected by a skeletal system running upwards past the antenno-labral apodeme through the *abc* sclerite and down to the lateral brace. At

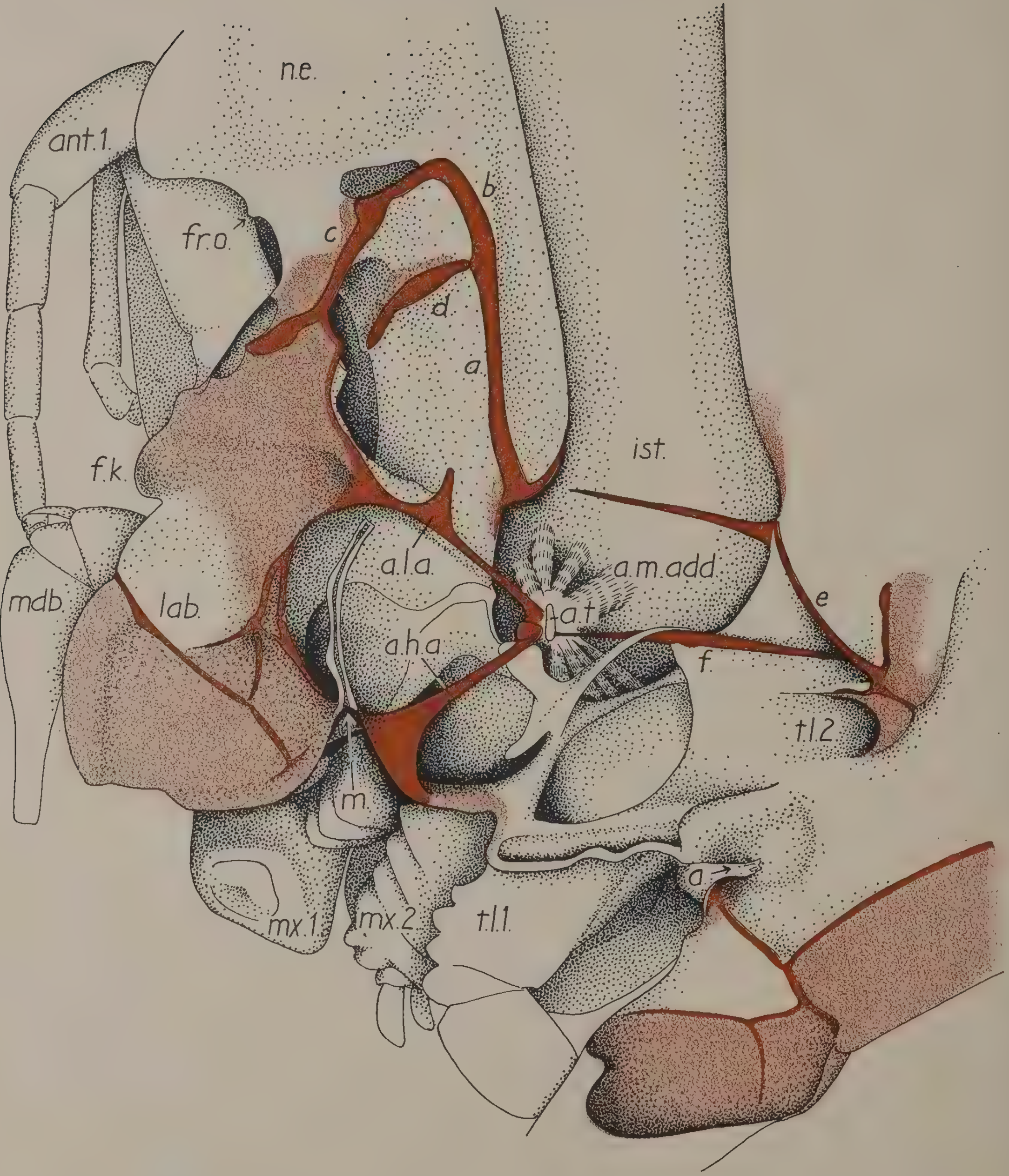


Fig. 4. Reconstruction of right anterior skin of *Gigantocypris* to show attachments of limbs to body, articulated sclerite system (*a–f*) and endoskeletal structures and their relation to the adductor muscle. The setal armature of the mouthparts has been omitted. *a.* anus; *a.h.a.* anterior hypostomal apodeme; *a.l.a.* antenno-labral apodeme; *a.m.add.* attachment of adductor muscle; *ant.*1, antennule; *a.t.* tendon of adductor muscle; *f.k.* frontal knob; *fr.o.* frontal organ; *ist.* isthmus; *lab.* labrum; *m.* mouth; *mdb.* mandible; *mx.*1, maxillule; *mx.*2, maxilla; *n.e.* nauplius eye; *t.l.*1, first trunk limb; *t.l.*2, second trunk limb.

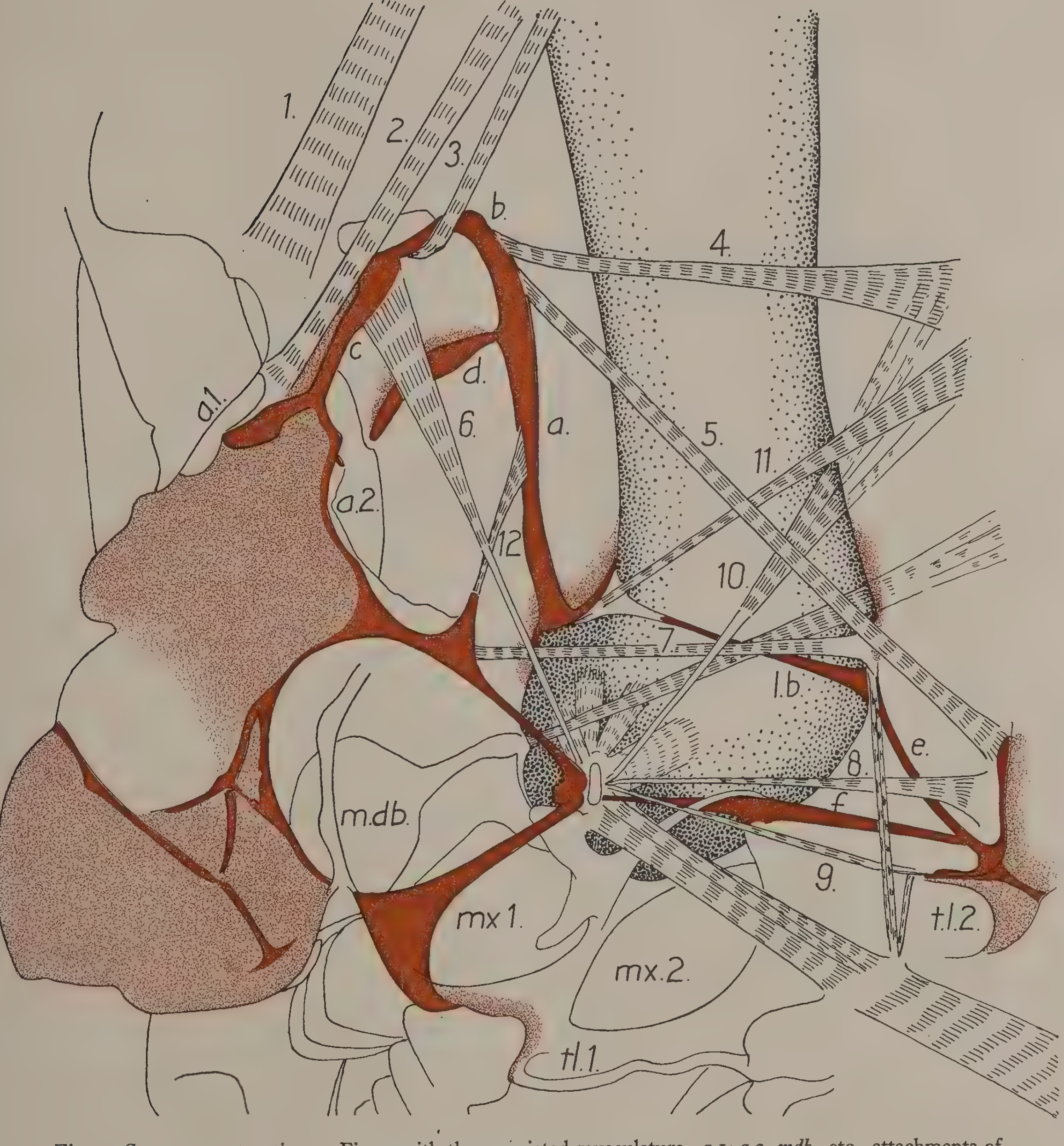

1.
2.
3.
b.
4.
c
d.
a.1.
6.
a.
5.
11.
a.2.
12
10.
7.
l.b.
e.
8.
f
m.db.
9.
mx 1.
t.l.2.
mx.2.
t.l.1.

Fig. 5. Same reconstruction as Fig. 4, with the associated musculature. *a.*1, *a.*2, *mdb.*, etc., attachments of limbs to body, *l.b.* lateral brace.

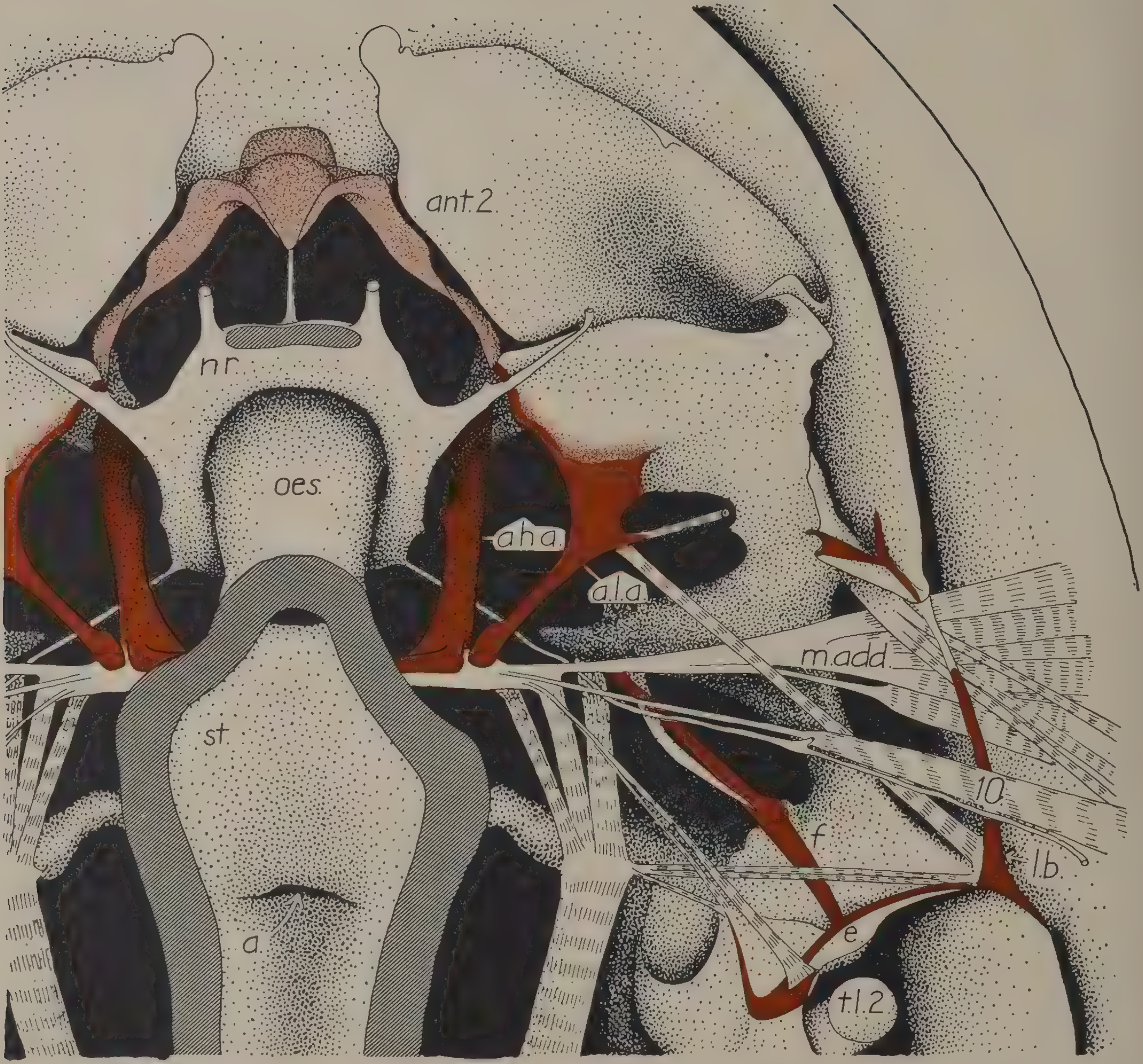


Fig. 6. Reconstruction of anterior part of body viewed from above to show the apodemal cönnexions to the adductor tendon. The anterior cardiac nerve has been inserted to show its passage up muscle 10 towards the heart. The base of the antennulary and antennal nerves have been included in the reconstruction; apart from this, the remaining nerves have been omitted. *a.* anus; *a.h.a.* anterior hypostomal apodeme; *a.l.a.* antenno-labral apodeme; *ant.*2, antenna; *l.b.* lateral brace; *m.add.* adductor muscle; *n.r.* nerve ring; *oes.* oesophagus; *st.* stomach; *t.l.*2, second trunk limb.

the other end of the lateral brace there is a thin sclerite *e*, which slopes downwards and backwards and markedly inwards (Fig. 6) to an L-shaped groove in the body wall in which lies the beginning of the second trunk limb (Figs. 4–6). In the anterior wall of this groove the *e* sclerite divides into two branches, one running upwards and the other at right angles running forwards.

I have called this system the articulated sclerite system because in *Doloria* the *abc* sclerite was certainly an articulated series of three separate sclerites. In *Gigantocypris* I am using the same name, but, as I have remarked, I cannot find any real articulation between the sclerites except in the minor case of the small *d* sclerites supporting the antenna. The sclerites, however, undoubtedly can be moved relative to each other as the muscular system demonstrates, but this must be through the flexibility of the system rather than its articulation. The skeletal rods in *Gigantocypris* are, relative to the animal, much more slender than those of the smaller form, *Doloria*, so that while in the latter articulations were necessary, in the giant form such movement can be brought about merely by the bending of one part or another.

It may be suggested that in such an enormous body as that of *Gigantocypris* any flexibility of the skeletal rods would render them too unstable to support any muscular movement. But the sclerite system is a series of rods in a very thin flexible body wall. The contraction of the dorsal muscular system which I have described produces continuously a high internal body pressure which will put this thin body wall in a state of tension. This will tend to restore any deformation of the narrow sclerites due to muscular activity, and so must render the sclerite system stable.

In Fig. 5 I have drawn the right sagittal half of *Gigantocypris* showing the sclerite system, and have inserted those muscles which are connected with it and with the adductor tendon.

The muscle numbered 1 is not strictly attached to the sclerite system. It runs from the lower median part of the nauplius eye to attach direct to the shell just below and lateral to the pericardium. It is one of a group of three parallel muscles whose position of upper attachment can be seen in Fig. 7*a* and Plate XXXIX, fig. 2. Of the other two, no. 2 is attached ventrally to the confluence of the *c* sclerites, just behind the antennules. No. 3 appears to slip under the *b* sclerite. It is, however, attached to the sclerite and at the same time to the lower margin of the vestigial paired eye. These three muscles must have a direct effect of raising the sclerite system and hence the whole front part of the body.

In isolated preparations muscle 3, the *b* sclerite, and the vestigial paired eye always remain firmly connected together. This muscle corresponds to the large postero-dorsal eye muscle that I describe but do not figure in *Doloria* (1931, p. 451). With the degeneration of the paired eyes in *Gigantocypris* the muscle has not disappeared; it has become relatively smaller and changed its function—instead of running under the *b* sclerite as a pulley it attaches to it and so assists the other muscles in lifting the anterior part of the body. The vestigial paired eyes are probably capable of being moved only as the sclerite system is moved for the other paired eye muscle—the anterior eye muscle—has disappeared.

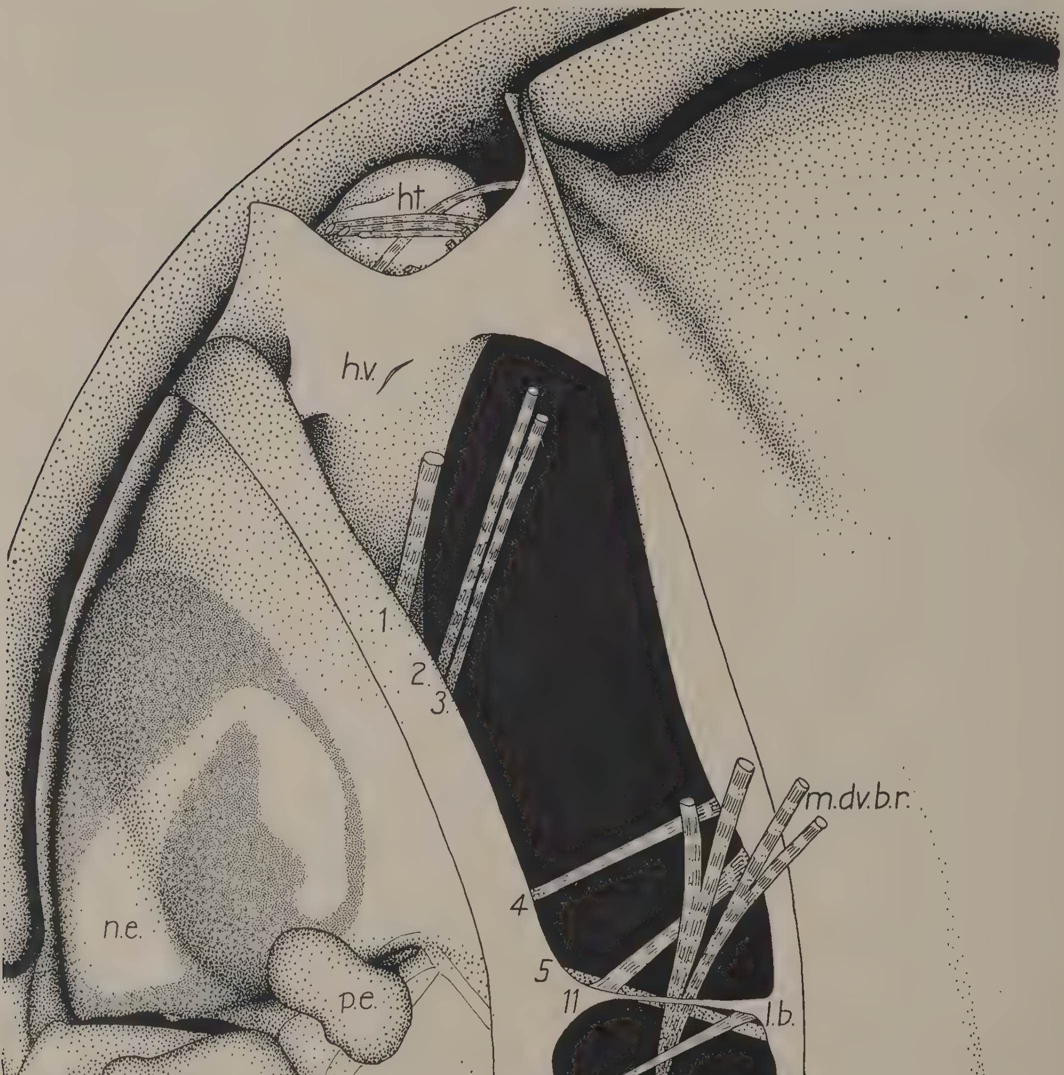

ht.
h.v.
1
2
3
4
5
11
m.dv.b.r.
l.b.
n.e.
p.e.
ant.2.
ant.1
e.
t.l.2
mdb.
mx.1.ep

Fig. 7*a*. Reconstruction of anterior part of body omitting the left valve, showing attachment of body to shell along margins of isthmus.

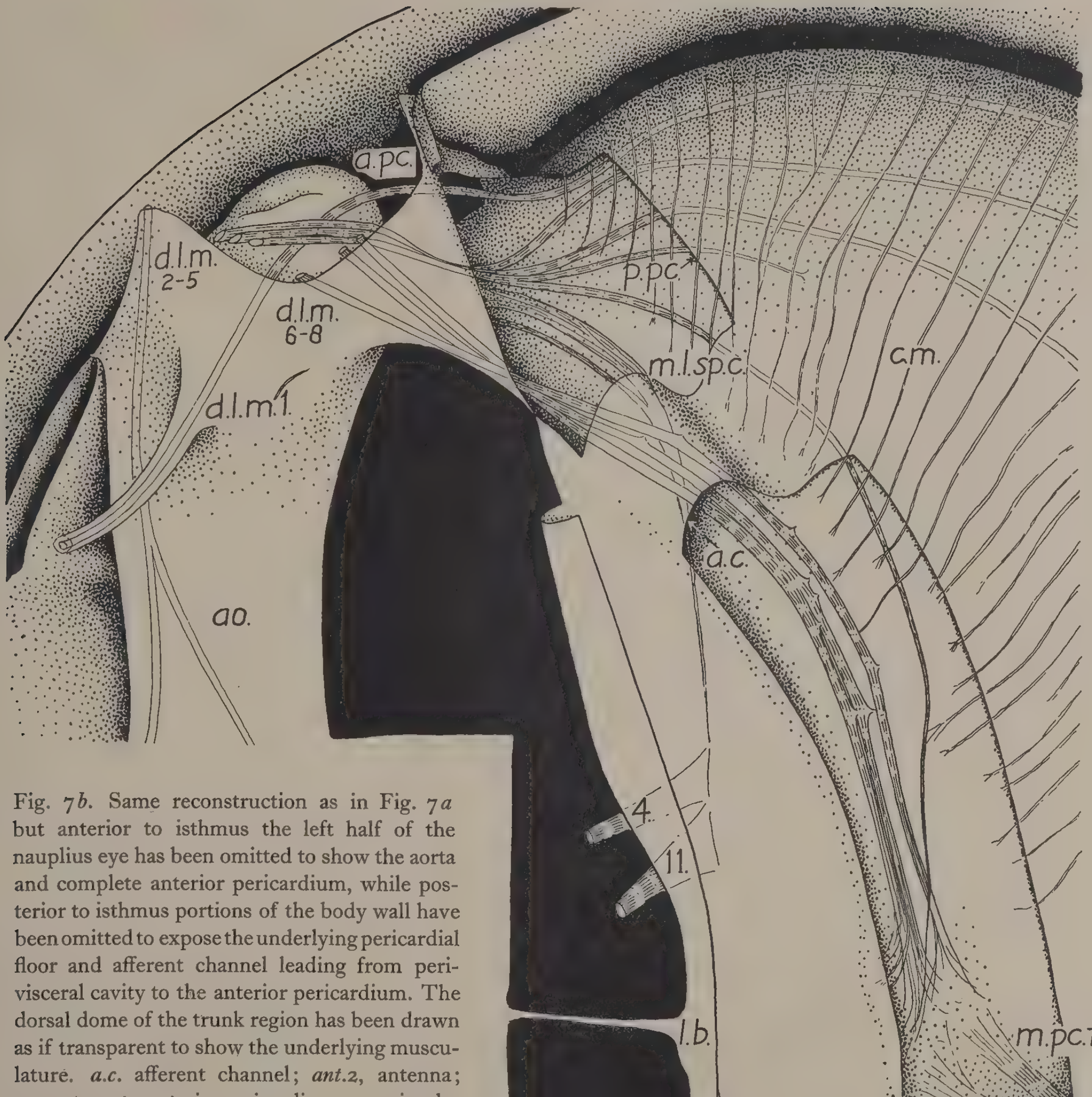


Fig. 7*b*. Same reconstruction as in Fig. 7*a* but anterior to isthmus the left half of the nauplius eye has been omitted to show the aorta and complete anterior pericardium, while posterior to isthmus portions of the body wall have been omitted to expose the underlying pericardial floor and afferent channel leading from perivisceral cavity to the anterior pericardium. The dorsal dome of the trunk region has been drawn as if transparent to show the underlying musculature. *a.c.* afferent channel; *ant.2*, antenna; *ao.* aorta; *a.pc.* anterior pericardium; *c.m.* circular muscle; *d.l.m.* dorsal longitudinal muscle; *ht.* heart; *h.v.* hepatic valve; *l.b.* lateral brace; *mdb.* mandible; *m.dv.b.r.* dorso-ventral body retractor system; *m.l.sp.c.* lateral subpericardial muscle; *m.pc.f.* pericardio-furcal muscle; *mx.l.ep.* maxillulary epipodite; *p.pc.* posterior pericardium; *pv.c.* entrance to perivisceral cavity; *t.l.2*, second trunk limb.

Muscle 4 runs from the top end of the tripod to attach to the mid-lateral body wall (Plate XLII, fig. 9). Muscle 5 attaches anteriorly just below muscle 4, but runs backwards to end on the upward branch of the *e* sclerite. Muscle 5 thus runs between two points directly connected by a skeletal rod system consisting of the *abc* sclerite, the lateral brace, and the *e* sclerite. If this system were not flexible the muscle would be useless. These two muscles, 4 and 5, must have a leverage action about the fixed point at the anterior end of the lateral brace, partly raising and partly pulling back the front part of the body.

Muscle 6 runs from the *c* sclerite to attach to the adductor tendon. This will similarly have a leverage action, but will lower and push forward the front part of the body. Muscle 6 can thus be looked upon as antagonistic to muscles 4 and 5.

Muscle 7 runs from the lateral extension of the antenno-labral apodeme backwards and outwards to the hinder end of the lateral brace. Muscle 8 runs from the adductor tendon to the upper posterior arm of the *e* sclerite, while muscle 9 runs from a similar place to the lower branch of the same sclerite. These muscles can all be seen, although they are not numbered, in Fig. 6. They are approximately parallel, and could assist the dorso-ventral body retractors in withdrawing the body inwards. Probably, however, they are not related to their function. Muscle 7 will have a powerful effect in pulling backward the median parts of the antennal attachments, while muscles 8 and 9 must represent a pair of antagonistic muscles capable of moving the attachment of the second trunk limb about the hind end of the *e* sclerite.

Muscle 10 is the dorso-ventral body retractor, the function of which I have already described (Fig. 8).

Muscle 11 (Plate XLII, fig. 5) runs from the anterior end of the lateral brace to attach alongside muscle 4 on the mid-lateral body wall. It probably functions in supporting this region of the body wall, a region which, as I shall explain in that part dealing with the blood system, is of great importance.

Muscle 12 runs from the *a* sclerite to the lateral extension of the antenno-labral apodeme as a depressor to the *abc* sclerite.

There is one more sclerite in the anterior system to be mentioned—the *f* sclerite—which appears to be quite independent of the rest. I mentioned it in *Doloria* but was unable to settle its extent accurately. It runs from the adductor tendon backwards and outwards to the body wall above the upper end of the vibratory plate of the maxilla (Fig. 6), but it has no connexion with the *e* sclerite (Figs. 4–6). About the middle of its length it bears an articulated sclerite which projects downwards and supports the vibratory plate of the maxilla, but as this can only be seen from an outside view of a sagittal half, it does not appear in Figs. 3 and 4.

Associated in a peculiar way with the *f* sclerite is a large and complicated apodeme which projects inwards between the maxillule and maxilla (Figs. 4–6). As this apodeme only appears to support the musculature of these limbs, it has not been coloured like the rest of the system, but it sends backwards an extension which curves over the top of the *f* sclerite and is attached to it at this point. In potash preparations the two structures separate, and this accounts for the incorrect position which I gave to the *f* sclerite in *Doloria* (1931, p. 442, fig. 2). The function of this backward extension would appear to be to give extra stability to the main support of the vibratory plate of the maxilla.

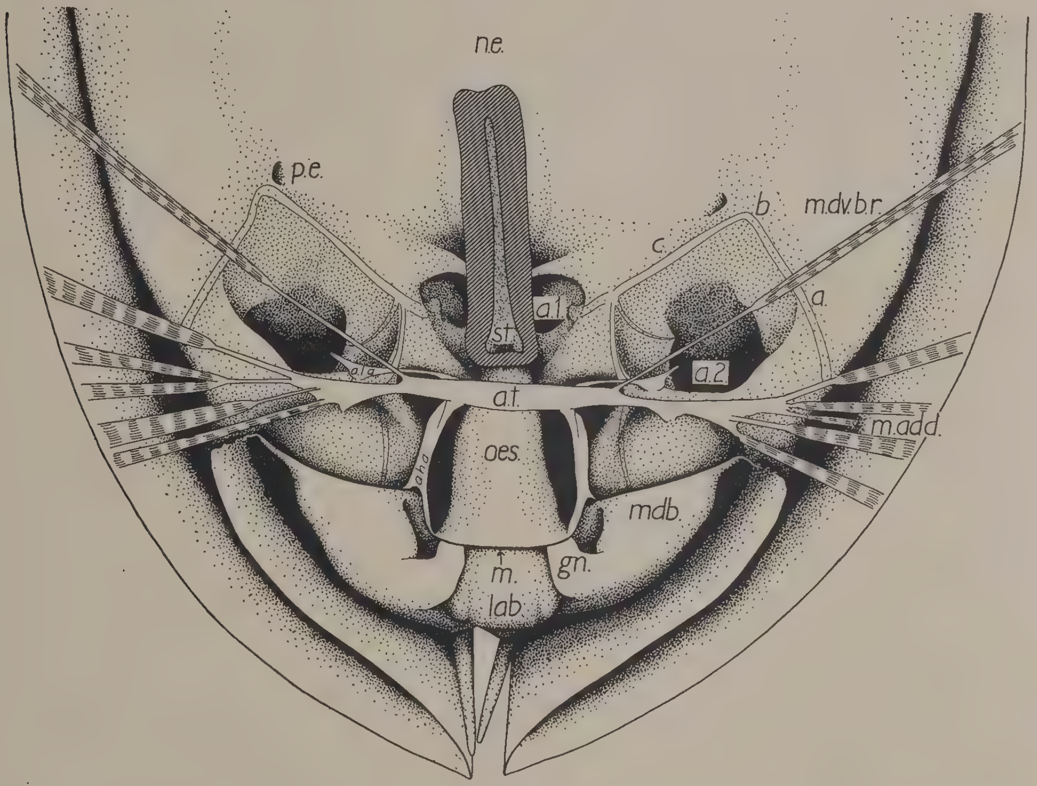


Fig. 8. Reconstruction of front part of *Gigantocypris* from the level of the adductor tendon viewed from behind to show the body retractor system and its relation to the endoskeletal system. The anterior hypostomal apodemes lie in the plane of the paper. The antenno-labral apodemes which are at right angles to the latter are thus mainly hidden by the adductor tendon. The setal armature of the mouthparts has been omitted. *a.*1, antennule; *a.*2, antenna; *a.h.a.* anterior hypostomal apodeme; *a.l.a.* antenno-labral apodeme; *a.t.* adductor tendon; *gn.* gnathobase of mandible; *lab.* labrum; *m.* mouth; *m.add.* adductor muscle; *mdb.* mandible; *m.dv.b.r.* dorso-ventral body retractor muscle; *n.e.* nauplius eye; *oes.* oesophagus; *p.e.* paired eye; *st.* stomach.

The caudal furca has its own system of sclerites which, as I have already mentioned, are quite separate from the rest of the skeleton. The muscles attached to the caudal furca which give it stability are the dorsal longitudinal series which attach directly to the shell at the side of the heart (Fig. 9) and a powerful pair of muscles which run forwards, and after attaching to the thin body wall between the caudal furca and the hinder margin of the first trunk limb, continue forwards as a group of three muscles on either side, to attach to the adductor tendon and to the apodeme between maxillule and maxilla (Fig. 6).

BLOOD SYSTEM

THE PERICARDIUM AND ASSOCIATED MUSCULATURE

The pericardial space, as in *Doloria*, consists of two distinct parts—the anterior or main pericardium in which lies the heart and the posterior pericardium extending into the trunk region.

I have described the attachment of the anterior pericardial floor to the body wall in *Doloria* as being, on each side, along a line like a distorted M. This arrangement is due to the presence of three sets of muscles whose attachments occupy the bays, two below and one above, formed by the M.

In *Gigantocypris* the first bay, with its associated muscles, is present and in a similar position. Of the muscles, however, while the aortic muscle and the nauplius eye muscle are well developed, there appears to be no trace of the anterior eye muscle which I described but did not figure (p. 451) for *Doloria*. This is not surprising considering the vestigial nature of the paired eyes.

The middle or upper bay has disappeared and is replaced by a long, drawn-out tube of pericardial floor (Fig. 7*b*). This has been brought about by the forward and outward migration of the attachment of the pericardial compressor muscle which the bay accommodates. The migration has gone to such an extent that the bay has been drawn out into a long V, until finally the two arms of the V have coalesced thus nipping off a small island around the muscle attachment.

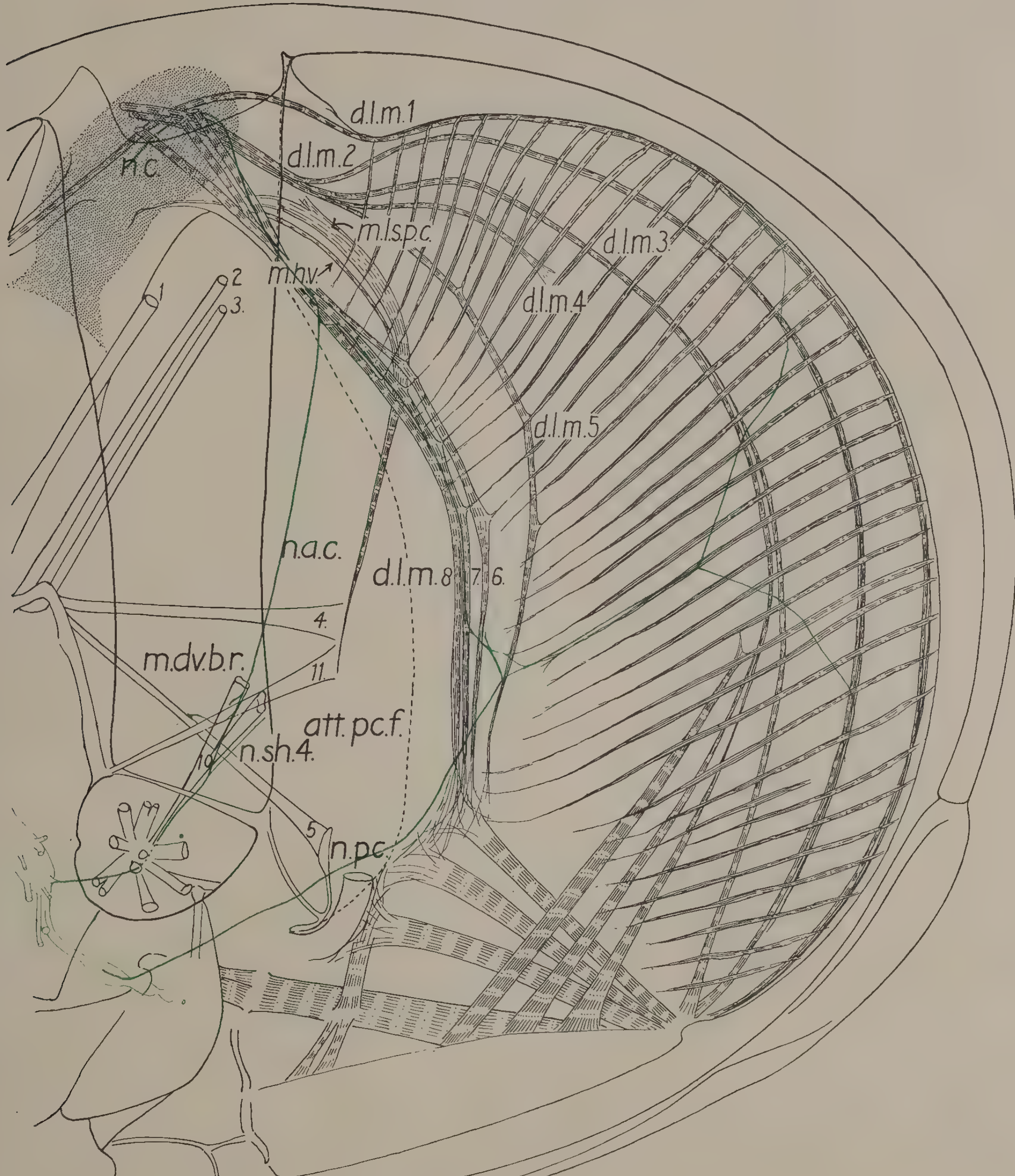
The third or posterior bay has disappeared. In *Doloria* it exists to accommodate the massive postero-dorsal eye muscle. As I have previously pointed out (p. 207), this muscle in *Gigantocypris* is relatively slender and functions as a levator muscle for the anterior sclerite system. Its point of attachment has migrated outwards so that it no longer impinges on the pericardial floor attachment and the latter has straightened out.

A comparison between the two anterior pericardia may be made by comparing Fig. 7 with Fig. 4*b* of *Doloria* (Cannon, 1931, p. 450).

The posterior pericardium is more extensive in *Gigantocypris* than in *Doloria*. As in the latter, it is divisible into right and left halves, the pericardial floor being confluent with the ectoderm down the middle line as far back as the caudal furca.

On either side the posterior pericardium consists of two parts—a postero-dorsal (morphologically dorsal) lacunar space and an antero-lateral tubular space, the afferent canal leading from the ventral part of the body cavity into the anterior pericardium.

The lacunar part of the pericardium extends just as far as the area covered by the circular muscles already described (p. 196, Fig. 9). Throughout this area the pericardial floor is a thin membrane attached to the inner surface of the dorsal longitudinal muscles and to the circular muscles and through these to the ectoderm. It thus reaches as far back as the caudal furca, and at the sides of the body to that indefinite zone where the circular muscles spread out into fibrils extending on the one hand into the ectoderm and on the other into the pericardial floor itself (Fig. 9).


n.c.
d.l.m.1
d.l.m.2
m.l.s.p.c.
d.l.m.3.
m.h.v.
2
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d.l.m.4
d.l.m.5
n.a.c.
d.l.m.8
7
6.
4.
m.dv.b.r.
11
att.pc.f.
10
n.sh.4.
5
n.pc.

Fig. 9. Reconstruction of hinder part of body, showing trunk musculature and cardiac nerve supply, seen from the animal's left side. The heart is machine stippled. *att.pc.f.* attachment of pericardial floor to lateral body wall; *d.l.m.* dorsal longitudinal muscle; *m.dv.b.r.* dorso-ventral body retractor muscle; *m.h.v.* branch of lateral subpericardial muscle running to hepatic valve; *m.l.s.pc.* lateral subpericardial muscle; *n.a.c.* anterior cardiac nerve; *n.c.* cardiac nerve; *n.p.c.* posterior cardiac nerve; *n.pc.* pericardiac nerve; *n.sh.*4, fourth shell nerve; *pc.f.* pericardio-furcal muscle.

Anterior to this the pericardial floor sinks into the body and then out again, thus forming a gutter (Fig. 7*b*) the anterior margin of which attaches to the lateral body wall along a line indicated in Fig. 9. Between this line and the posterior margin of the isthmus of attachment of body to shell there is no pericardial space. This gutter that I have just described is the afferent channel leading into the main pericardium (Plate XLII) and corresponds to the branchio-cardiac canals of the Crayfish. It differs from the latter in leading from the general body cavity and not from gills, and corresponds to the similar channels described by Lowe (1935, p. 579) in *Calanus*.

The dorsal longitudinal muscles are closely similar to those of *Doloria*, but in the latter I think that I described some of the attachments incorrectly owing to the difficulty in tracing the actual extent of the pericardial floor. In *Gigantocypris* this is never in doubt, and I feel certain that the attachments I am now going to describe would apply to any ordinary Cypridinid (Fig. 9).

Enumerating the dorsal longitudinal muscles from the median line outwards, the first muscle extends from the anterior attachment I have described in detailing the outline of the anterior pericardium (p. 212). It runs obliquely inwards and backwards and attaches to the ectoderm just lateral to the middle line at the hinder margin of the anterior pericardium. The pair of muscles then run parallel to each other backwards to the caudal furca, being closely attached to the ectoderm throughout their length. The anterior part of these muscles will form the pericardial compressor muscles—the posterior part, the first dorsal longitudinal muscle.

The second, third, fourth and fifth dorsal longitudinal muscles attach anteriorly in a group direct to the outer shell of the valves which forms the lateral wall of the anterior pericardium. The second and third muscles run backwards to the caudal furca, as does the first, but none of these three run over this length as continuous muscle. They all gradually dwindle posteriorly and become a tendinous strand attaching near the caudal furca, but in each case as they dwindle they are replaced by a tendinous attachment which, on the contrary, increases in size and becomes muscular as it passes posteriorly (Fig. 9). Because of this, sections of the body wall give the appearance of thin muscles of uniform thickness running continuously over this stretch. It is only carefully stained preparations of the whole body wall which show the oblique discontinuity in the muscles.

The fourth dorsal longitudinal muscle is short and attaches to the ectoderm after having traversed only about one-quarter of the length of the dorsal dome (Fig. 9 and Plate XLII, figs. 1–4). It may be that it is a portion of the fifth muscle which has split off, as its anterior attachment is the same as that of the fifth.

The fifth dorsal longitudinal muscle runs backwards and downwards in an arc, just projecting into the lacunar region of the posterior pericardium, but then emerging again ventrally to disappear as a mass of tendo-fibrils in the actual pericardial floor at the lower end of the afferent canal (Plate XLII, figs. 2–11).

In this same region are attached the ventral tendinous portion of the sixth, seventh and eighth dorsal longitudinal muscles (Plate XLII, fig. 8). These run upwards in the afferent canal, curving forwards and inwards to attach to the outer shell forming the wall of the anterior pericardium. As they emerge into the main pericardium they twist over each other so that the most anterior, the eighth, comes to attach most posteriorly and vice versa.

The extent of these dorsal longitudinal muscles is shown clearly in Fig. 9 and in Plate XLII. The attachments of the outer muscles to the pericardial floor are shown in Fig. 7*b* where the body wall, covering and so forming the roof of the afferent canal, has been removed to expose its floor.

In *Doloria* (1931) I described this lateral group of dorsal longitudinal muscles and stated that at their lower ends they attached directly to the ectoderm (p. 452). This statement, I am certain now, is incorrect. The small size of *Doloria*, but more particularly the fact that I was using ordinary paraffin sections, made it very difficult to settle where the muscles actually attached. I have re-examined the sections and find that the pericardial floor is close up against the ectoderm, probably as a result of technique employed. In the celloidin slices of *Gigantocypris* there is no distortion of the tissues, and I can trace the lower termination of these muscles without any doubt as a mat of tendo-fibrils in the pericardial floor itself (Plate XLII, figs. 5–8).

From the hinder limit of the caudal furca a group of three broad muscles, the pericardio-furcal muscles, radiate forwards, upwards and outwards (Fig. 9). The lowest of these attaches to the *e* sclerite system associated with the second trunk limb, just where the pericardial floor attaches to the body wall. The upper attaches to the pericardial floor at the lower end of the afferent canal, its tendo-fibrils mingling with those of the outer dorsal longitudinal muscles (Fig. 7*b*). The middle muscle attaches in an intermediate zone, but the tendo-fibrils at the upper ends of all three muscles spread out and intermingle. More important, however, is the fact that they intermingle with the mat of tendo-fibrils forming the lower ends of the outer series of dorsal longitudinal muscles.

This tendo-fibrillar zone at the bottom of the afferent pericardial canal is thus held in position from three directions. Anteriorly it is attached directly to the *e* sclerite and so to the main skeletal system. Postero-medially it is connected to the caudal furca. Dorsally it is connected by the dorsal longitudinal muscles direct to the shell at the sides of the main pericardium. This dorsal connexion, however, is in effect dorso-medial, for the upper attachments are much nearer the middle line than are the lower, as can be seen from the series of sections shown in Plate XLII.

Contractions now, of the pericardio-furcal muscles, will pull inwards, downwards and backwards the floor of the lower end of the afferent pericardial canal. The back pull will be resisted by the skeletal system through the *e* sclerite. The inward pull will open up the entrance to the canal from the main body cavity. The downward pull will be counteracted by the upward pull of the lateral series of dorsal longitudinal muscles. This series, however, lying on the floor of the afferent channel and curving inwards as it passes upwards will, by its contraction, at the same time tend to depress inwards the floor of the canal over the whole of its length. These two sets of muscles, therefore, the pericardio-furcal muscles together with the lateral series of dorsal longitudinal muscles, I consider function by controlling the bore of the main afferent blood channel leading into the pericardium. On their contraction the canal becomes a wide open tube. On relaxation the internal pressure produced by the dome of circular and longitudinal muscles will press the floor of the canal against the ectoderm forming its roof and so close it. The functions of these two sets of muscles are therefore what I ascribe solely to the lateral subpericardial muscle in *Doloria*. The interaction of the muscles associated with the pericardium during the complete heart beat, which I described for *Doloria* (Cannon, 1931, p. 456 and Fig. 7, p. 460), is not upset by this change. If to the name "lateral subpericardial muscles" is added "lateral series of dorsal longitudinal muscles" the same argument applies.

The lateral subpericardial muscle is attached directly as a thin powerful strand to the mid lateral body wall, in that zone between the afferent canal and the isthmus of attachment of body to shell (Fig. 9). From the point where it disappears as tendo-fibrils in the body wall two muscles are attached, which I have previously numbered as 4 and 11 (Plate XLII, figs. 9, 10). Of these, no. 4 is used to move the upper part of the tripod in the sclerite system and is of little significance in connexion with the muscles we are discussing. No. 11, however, runs across the isthmus to attach at the base of the *a* sclerite, at a point which, from my previous description, and as can be seen from Fig. 5, is one of the most stable points in the whole body. The lateral subpericardial muscle is thus connected firmly to the main skeletal system.

At its lower end, immediately above its tendinous attachment, it is definitely a striated muscle, but as it passes dorsally and enters the pericardial floor it spreads out and its striations become less marked until when it enters the main pericardium its myofibrils are continuous. In *Doloria* I described it as disappearing towards the region of the hepatic valves. In *Gigantocypris* I have been able to follow its course accurately. As it passes over from the afferent canal into the main pericardium it spreads out into several branches. The most posterior branch extends almost directly inwards, disappearing towards the middle line. The more anterior branches behave in a similar way but extend proportionately more forwards. In fact all branches, except the most anterior which is a thin strand, extend towards the middle line and so towards their fellows from the opposite side. As a result of this arrangement the pair of muscles must form an arch, the bases of which are firmly connected to the main skeleton. Contraction of the pair of muscles together must therefore pull down the roof of the arch, or, in other words, depress the floor of the main pericardium. Individually they will at the same time depress the floor of the upper end of the afferent canal and so aid the lateral series of dorsal longitudinal muscles in opening up this passage.

The thin strand which forms the most anterior branch of this spreading muscle I have traced forwards to the hepatic valve itself (Fig. 10).

THE HEART VALVES

The pair of postero-dorsal ostia call for no special comment.

The paired hepatic valves lead directly into the gut parenchyma. I pointed out (Cannon, 1931, p. 449) that Lüders was undoubtedly incorrect in stating that blood passed into the heart through these gaps from the gut region. My sections of *Gigantocypris* have supported this view, for in fixation the blood cells become grouped on the heart side of the valve (Plate XLI, fig. 8) showing that they are efferent valves. The tubes into which the valves open are very definite vessels whose walls are formed by the parenchyma cells. They can be traced backwards where, at the sides of the stomach, they bifurcate, the branches becoming smaller and finally disappearing in the interstices of the parenchymatous tissue.

Both the hepatic valves and the aortic valve are associated with very distinct gaps in the heart musculature. The oval, bean-shaped opening leading to the right hepatic valve is clearly shown in side view in Fig. 10. The right half of the narrow oval opening leading to the aortic valve is seen in the same figure.

In *Doloria* I stated that the edges of the gaps are fused with the pericardial floor. In *Gigantocypris*, however, this is not so. The valves are actually at some distance from the muscular wall of the heart, the intervening gap being joined by a squat tube (Fig. 15). The walls of these efferent tubes appear to consist of a very thin membrane in which there are a few striated muscles running approximately in the same direction as the nearby heart musculature. They are not formed from accumulations of the parenchymatous cells which in other places extend over the heart surface, such as I described in *Doloria*. The latter form a branching network, while the walls of these efferent tubes are definite membranes. The tubes are closed at the outer ends by the pericardial floor, and the valves consist simply of splits in the latter. The edges of the splits show a distinct fibrillation (Plate XLI, fig. 8) but without any cross striation.

The fibrils of the hepatic valve extend posteriorly into the most lateral branch of the lateral subpericardial muscle. Anteriorly they do not appear to extend beyond the limit of the valve itself, but from this point there is a radiation of fibrils in the pericardial floor which undoubtedly affords the anterior support for this muscle.

The fibrils of the aortic valve, which are much more distinct and extensive than those of the hepatic valves, narrow down anteriorly to attach to the front of the upper end of the aorta on a level with the top of the nauplius eye. This is the same level of attachment as in *Doloria*, but in the latter the attachment went right through to the ectoderm. Here the attachment is to the aortic wall and the aorta is free from the ectoderm. Posteriorly the valve narrows down to a tendinous connexion to the pericardial dilator. In *Doloria* I have described this muscle as being continuous dorsally with a median muscular strip of the pericardial floor which I term the median subpericardial muscle. This distinction should probably not have been made, as in *Gigantocypris* the pericardial dilator only extends a short distance above the attachment of the aortic valve, where it disappears into the pericardial floor (Fig. 10).

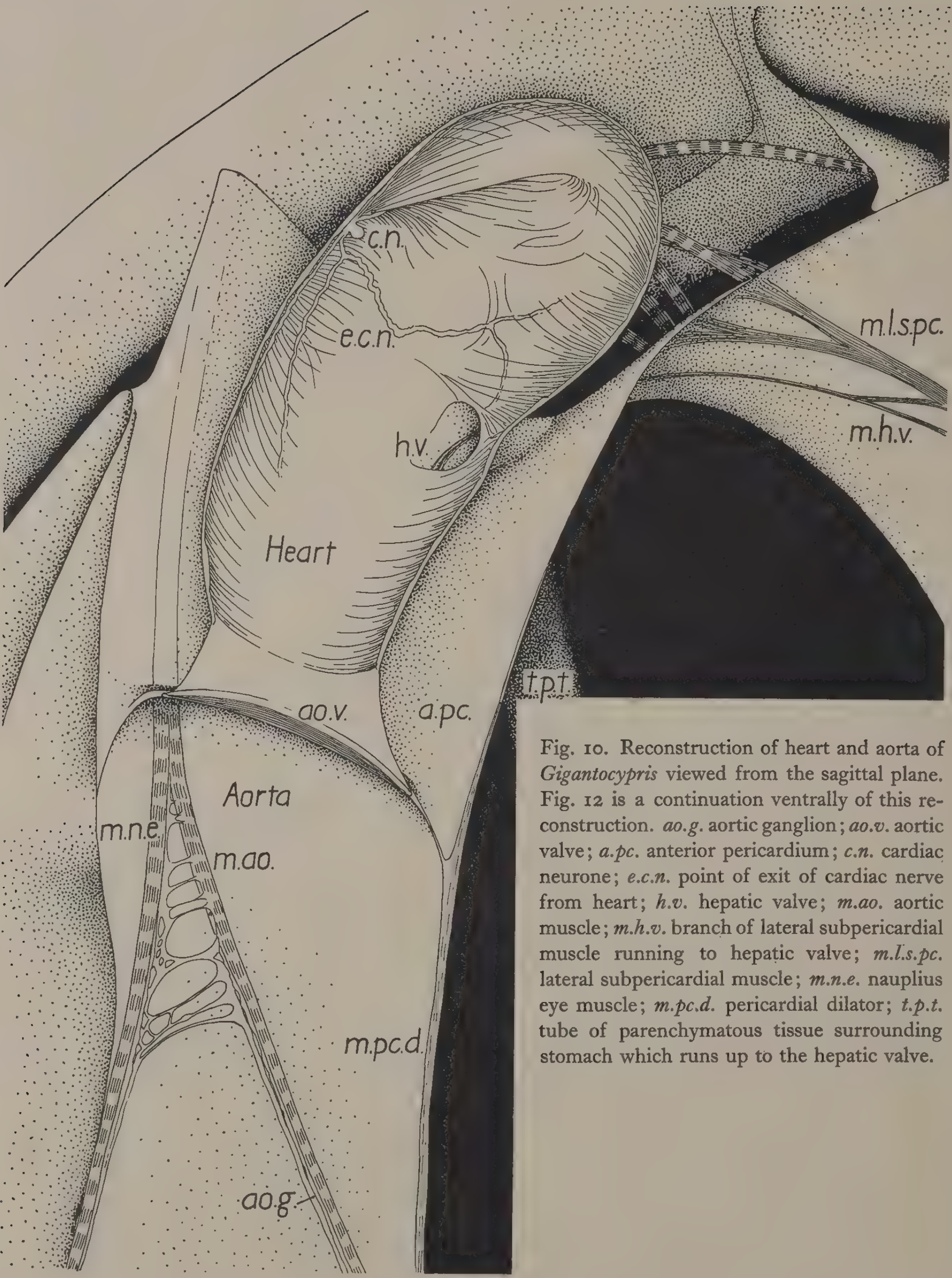

Fig. 10. Reconstruction of heart and aorta of *Gigantocypris* viewed from the sagittal plane. Fig. 12 is a continuation ventrally of this reconstruction. *ao.g.* aortic ganglion; *ao.v.* aortic valve; *a.pc.* anterior pericardium; *c.n.* cardiac neurone; *e.c.n.* point of exit of cardiac nerve from heart; *h.v.* hepatic valve; *m.ao.* aortic muscle; *m.h.v.* branch of lateral subpericardial muscle running to hepatic valve; *m.l.s.pc.* lateral subpericardial muscle; *m.n.e.* nauplius eye muscle; *m.pc.d.* pericardial dilator; *t.p.t.* tube of parenchymatous tissue surrounding stomach which runs up to the hepatic valve.

BLOOD VESSELS

In *Doloria* the heart opens obliquely into the anterior end of an aorta which lies directly on the anterior end of the nerve ring (Cannon, 1931, p. 450, fig. 4), and runs backwards to a point where it bifurcates and encircles the oesophagus. This point is marked by a median apodeme which runs inward from just above the frontal knob through the nerve ring close against the hinder wall of the brain to attach at its inner end to the hinder wall of the aorta where the latter bifurcates. In *Gigantocypris* the same state of affairs obtains, but here the nerve ring is situated far from the heart. The region between the heart and the upper end of the labrum, which marks the level of the nerve ring, has become very much stretched (p. 192) to accommodate the enormous nauplius eye. Hence the aorta has become correspondingly stretched to form a large tube projecting, not backwards, but downwards to meet the nerve ring.

The increase in length of the aorta can thus be accounted for, but at the same time it has increased very considerably in transverse section. Similarly, the heart is relatively enormous. This can be seen clearly by comparing Fig. 4 of *Doloria* (Cannon, 1931, p. 450) with Fig. 10 of *Gigantocypris*, both of which show a sagittal section through heart and aorta. In *Doloria* the section of the heart is about the same area as that through the brain. In *Gigantocypris* it is about fourteen times the area (Figs. 10, 12). Thus the heart of *Gigantocypris* is, relative to the nervous system, about fifty times as big as that of the smaller Cypridinid. This large size is certainly emphasized by the fact that the nerve ring of *Gigantocypris* is relatively small, but not markedly so, when it is compared with such a structure as the labrum (Figs. 11, 12). Even allowing for this however and making a very rough comparison with the ventral body as a whole, the heart will be about twenty times as big. Now the size of a heart can be taken as a direct measure of its power, and why *Gigantocypris* should require a heart twenty times as powerful to pump its blood into the body cavity is a fact for which at present I have no explanation to offer.

In the anterior wall of the aorta lies a pair of muscles (Figs. 10, 12). These are the nauplius eye muscles that I described in *Doloria*. In the latter form, however, they are completely outside the aorta. In *Gigantocypris* at their lower ends they are attached to the wall of the aorta, the muscle projecting into the lumen. Dorsally, above the level of the aortic valve, they pass from the aorta into the pericardial floor, but their muscle bodies project outwards.

The attachments of the muscles are the same in the two forms. Dorsally they occupy a bay in the attachment of the pericardial floor which I have already mentioned (p. 212). Ventrally, in *Doloria* they attach to a point in the mid-ventral region of the nauplius eye. There is a ventral connexion to the ectoderm and also paired lateral connexions to the more lateral ectoderm covering the eye. In *Gigantocypris* these same three connexions are present, but are considerably elongated owing to the enormous development of the nauplius eye. The lower end of the muscles marks the level at which ectodermal strands extend inwards from the sides. The median connective, however, is a definite apodemal intucking (Fig. 12).

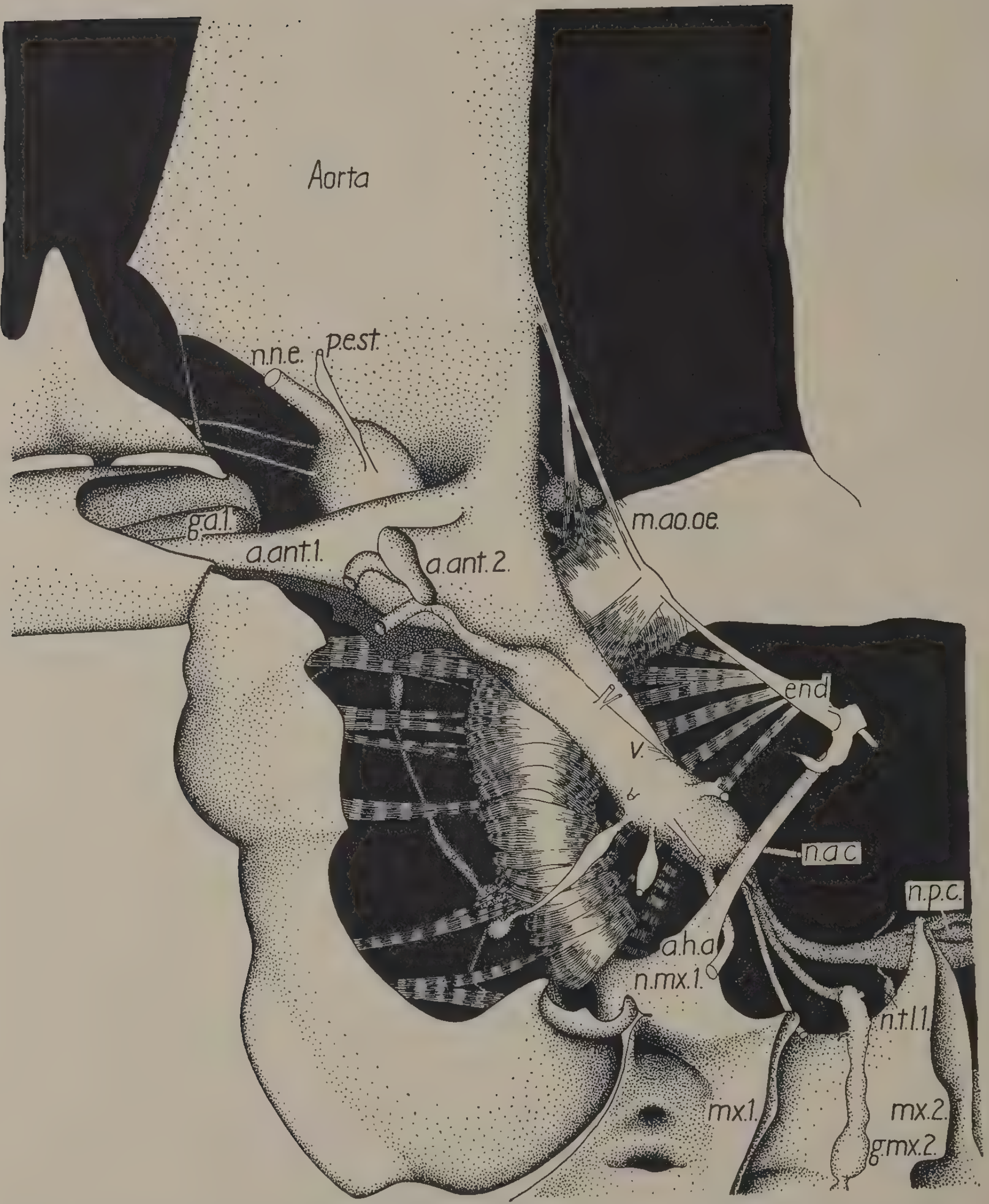

Fig. 11. Reconstruction of anterior part of body from a parasagittal plane so chosen as to expose the aorta and the complete nerve ring surrounding the oesophagus. Only certain nerves have been labelled; the remainder can be identified by comparison with Fig. 13. *a.ant.*1, antennulary artery; *a.ant.*2, antennal artery; *a.h.a.* anterior hypostomal apodeme; *end.* endosternite; *g.a.*1, basal ganglion of antennule; *g.mx.*2, basal ganglion of maxilla; *m.ao.oe.* aortic-oesophageal muscle; *n.n.e.* nerve to lateral component of nauplius eye; *mx.*1, maxillule; *mx.*2, maxilla; *n.a.c.* anterior cardiac nerve; *n.mx.*1, maxillulary nerve; *n.p.c.* posterior cardiac nerve; *n.t.l.*1, first trunk limb; *p.e.st.* stalk of paired eye; *v.* termination of valve controlling supra-neural vessel.

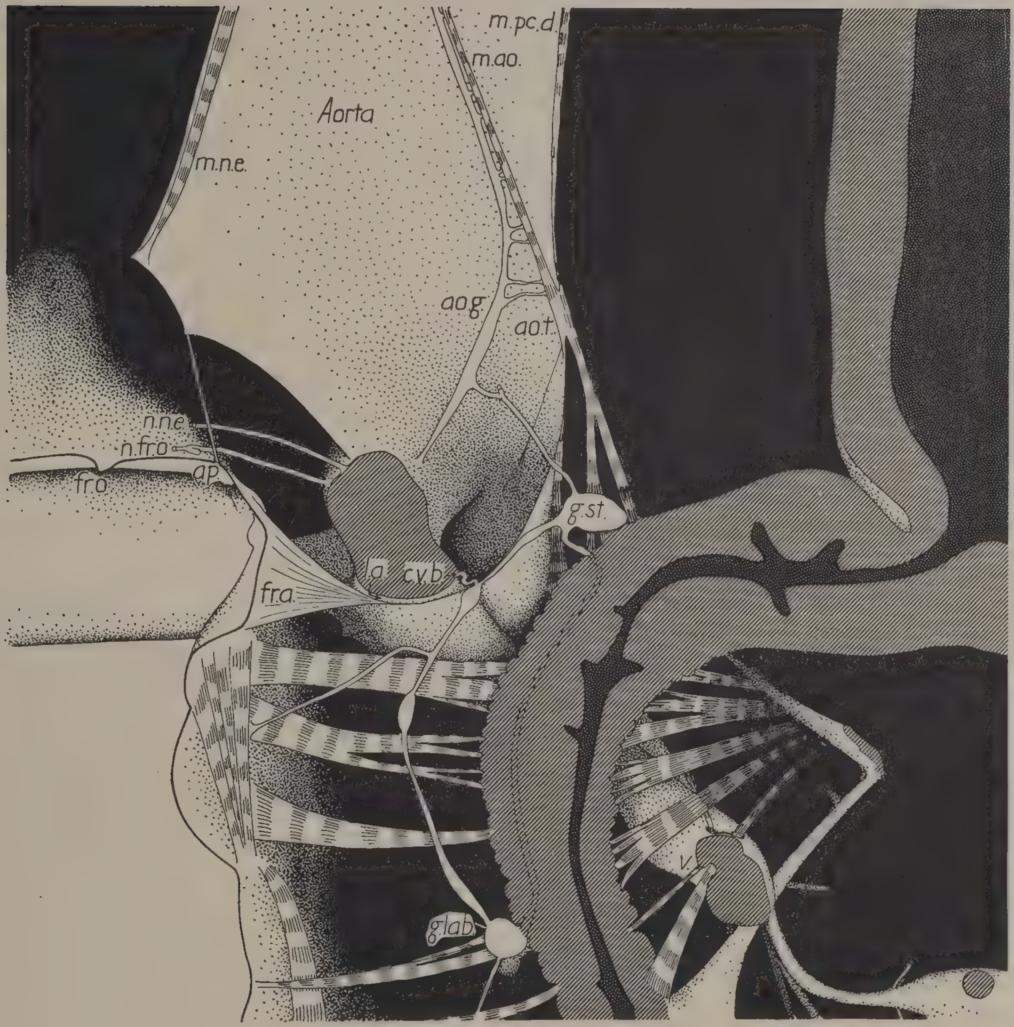

Fig. 12. Same reconstruction as in Fig. 11 but from the sagittal plane showing aorta and nerve ring accurately bisected and complete visceral nervous system. *ao.g.* aortic ganglion; *ao.t.* aortic tendon; *ap.* apodeme supporting nauplius eye muscle; *c.v.b.* connexion between visceral system (labral loop) and brain; *fr.a.* frontal apodeme; *fr.o.* frontal organ; *g.lab.* labral ganglion; *g.st.* stomach ganglion; *l.a.* labral artery; *m.ao.* aortic muscle; *m.n.e.* nauplius eye muscle; *m.pc.d.* pericardial dilator; *n.fr.o.* nerve to frontal organ; *n.n.e.* nerve to median component of nauplius eye; *v.* valve in supraneural blood vessel.

In the posterior wall of the aorta lies the pericardial dilator muscle. This extends from the pericardial floor down to a tendinous plate in the aortic wall just above the level where the aorta bifurcates. This plate, the aortic tendon, marks the point of attachment of various muscles and is itself connected to the ectoderm through the frontal apodeme (Fig. 12). The muscles are the anterior and posterior aortic-oesophageal muscles and the aortic endosternite muscle all running ventrally, while the aortic muscles run dorsally, to meet the nauplius eye muscles. All these muscles and the endosternite have the same relationships as in *Doloria*. The latter is not, however, a thick plate as in the more typical Cypridinid but is a very thin tendinous sheet whose actual limits are very difficult to determine.

At its lower end the aorta divides into several branches. Medially it leads into a very narrow but definite vessel between the frontal apodeme ventrally and the lower (or hinder) wall of the brain dorsally (Fig. 12). I found no trace of such a vessel in *Doloria*, but if it existed it would have been excessively minute. Its presence in *Gigantocypris* is easy to establish because the lowermost wall of the aorta has spread over it a plexus of nerve fibres (see p. 231), and these can be traced from the aortic tendon as a sheet right through the nerve ring and then upwards to the frontal apodeme. The latter is an extremely thin membranous plate in the median plane, so that blood passing from the aorta through this channel would pass on either side of it into the upper end of the labrum. I am therefore labelling this lacunar vessel the labral artery (Fig. 12).

Laterally the aorta divides at its lower end into the two large vessels lying directly on the nerve ring. In *Doloria* these two encircled the oesophagus and joined posteriorly to form the supraneural ring vessel. In *Gigantocypris* they lie on the nerve ring but do not join, and hence I call them the supraneural vessels.

At their commencement they each give off a large vessel which runs forward and into the antennules (Fig. 11). It can be traced in sections through most of the length of this limb. Soon afterwards, and more laterally, they give off a very large vessel which runs direct into the antennae where it opens in the neighbourhood of the antennal gland.

Posteriorly the supraneural vessels narrow down to an extremely small opening controlled, as in *Doloria*, by a valve (Figs. 11, 12). This valve muscle is apparently a modified oesophageal dilator, for its lower attachment is in series with the posterior oesophageal dilators which are running in to attach to the endosternite. It can be traced upwards, through the paired apertures of the tritocerebral region of the brain to the supraneural vessel. At its upper end the muscle swings outwards and appears to terminate in connective tissue in this region (Fig. 11).

NERVOUS SYSTEM

GENERAL ACCOUNT

The account of the nervous system given by Lüders (1909, pp. 33–9) is remarkably complete considering the scarcity of his material. It is, however, a relatively easy dissection to remove the entire nervous system, and this is presumably what Lüders did, but, as a consequence, he overlooked some of the largest and most important nerves. He arranged the nerves extending laterally from the massive nerve ring in groups corresponding to the limbs and so did not discover that among these nerves there are four which run to the shell and adductor muscle. A point more difficult to understand is that he overlooked the very well developed visceral system.

He remarks (p. 37) on the marked difference between the nervous system of *Gigantocypris* and that of other Ostracods. It must be remembered however that, at that date, no nervous system of a Cypridinid had been described in any detail. Actually, the nervous system of *Gigantocypris* differs little from that of a typical Cypridinid such as I described for *Doloria*, except in the enlargement of the nerve ring and the larger posterior chain system. The former difference is, of course, a direct consequence of the distended shape and size of *Gigantocypris*. The latter is a point taken by Lüders to indicate the primitive nature of *Gigantocypris*. I do not agree with this conclusion, and deal with it later (see p. 228).

A remarkable character in which *Gigantocypris* differs from *Doloria* is that the nerve ring is enclosed in a definite sheath of connective tissue which, while investing the nervous matter closely in the posterior part of the ring, extends a considerable distance away from the actual nerve cells in the anterior part (Lüders, 1909, p. 35). There is thus a marked empty space between the brain proper and its neurilemma. At first sight, both in Lüders' published figure and in my own preparations, I attributed this space to shrinkage resulting maybe from poor fixation or as a consequence of the depth from which the animals were obtained. I soon found, however, that the "Discovery" specimens are exceedingly well fixed and there was no evidence either of distension or collapse. From the complete agreement between Lüders' figure (1909, plate 8, fig. 23) and my photographs (Plate XLI, fig. 2 and Plate XL, fig. 1) and from the constancy of the shape and extent of this space in all my series of sections, I am convinced that this is no artefact but a real space occurring in the living animal. The investing sheath is no delicate membrane but a relatively thick sheet of tissue staining bright orange in Mallory. No trace of it occurs in *Doloria*. I can suggest no function for it and do not know of any other case in an Arthropod brain.

At the front end of the brain is a group of five nerves, the points of origin of which are so arranged that one is in front and the other four are arranged in a transverse row. The most anterior nerve runs to the relatively small median portion of the nauplius eye, and soon after passing through the neurilemma swells up into a ganglion. It is not always symmetrically placed as in Fig. 13. It sometimes arises to one side of the median

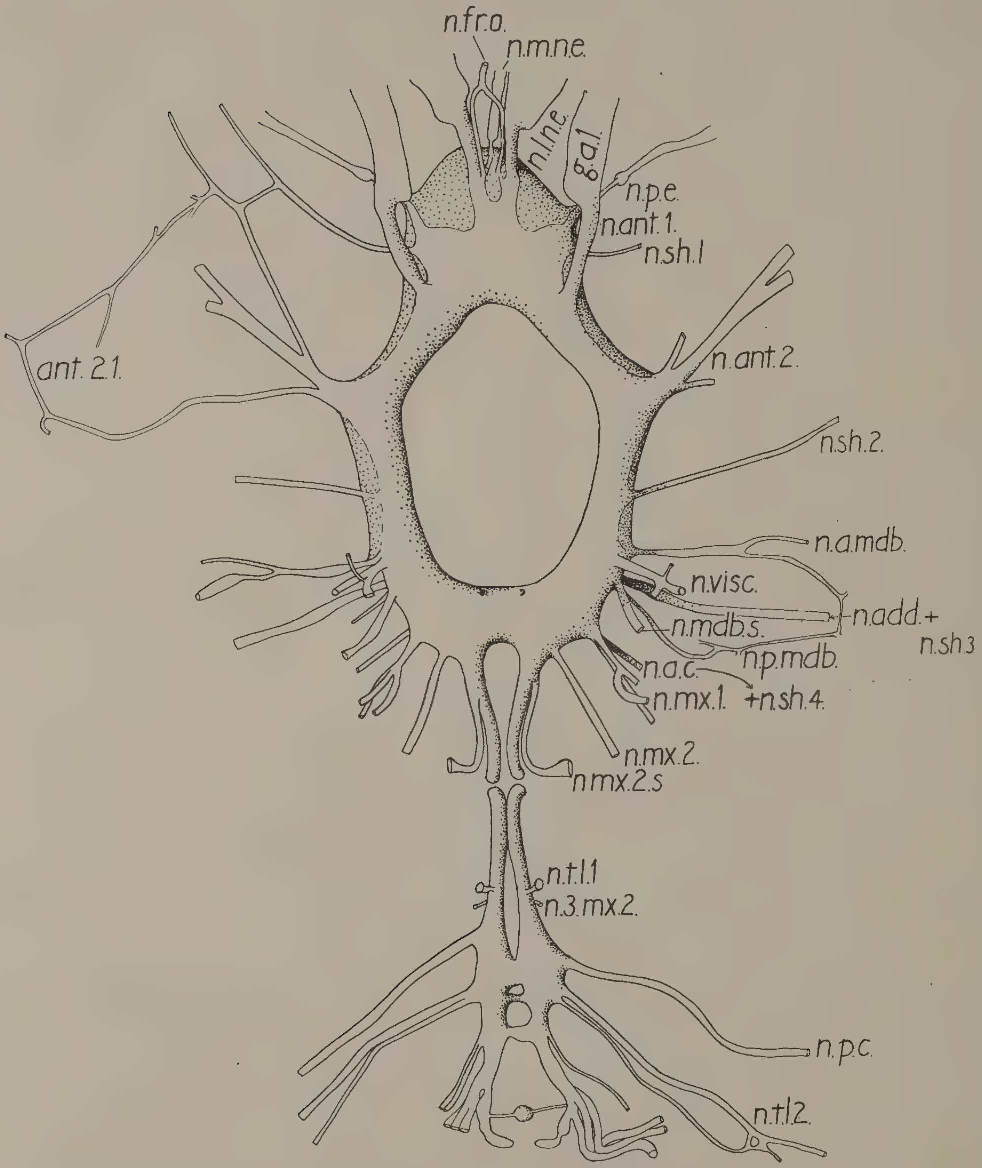
n.fr.o.
n.m.n.e.
n.l.n.e.
g.a.1.
n.p.e.
n.ant.1.
n.sh.1
ant. 2.1.
n.ant.2.
n.sh.2.
n.a.mdb.
n.visc.
n.add.+
n.sh3
n.mdb.s.
n.p.mdb.
n.a.c.
n.mx.1.
+n.sh.4.
n.mx.2.
n.mx.2.s
n.t.l.1
n.3.mx.2.
n.p.c.
n.t.l.2.

Fig. 13. Reconstruction of nervous system. As the plane of the nerve ring is at about 120° to that of the chain system (see Fig. 11), the reconstruction of the nerve ring was made from one series of sections and that of the chain system from another. The sections on which these drawings are based are illustrated by photographs on Plate XL, figs. 1–8. *ant.2.l.* nerve loop ramifying over antennal gland; *g.a.1*, basal ganglion of antennule; *n.a.c.* anterior cardiac nerve; *n.add.* nerve to adductor muscle; *n.a.mdb.* anterior mandibular nerve; *n.ant.1*, antennulary nerve; *n.ant.2*, antennal nerve; *n.fr.o.* frontal organ nerve; *n.l.n.e.* nerve to lateral component of nauplius eye; *n.mdb.s.* sensory mandibular nerve; *n.m.n.e.* nerve to median component of nauplius eye; *n.mx.1*, maxillulary nerve; *n.mx.2*, maxillary nerve; *n.mx.2.s.* sensory maxillary nerve; *n.3.mx.2*, third maxillary nerve; *n.p.c.* posterior cardiac nerve; *n.p.e.* nerve to paired eyes; *n.p.mdb.* posterior mandibular nerve; *n.sh.1–4*, shell nerves 1–4; *n.t.l.1*, first trunk limb nerve; *n.t.l.2*, second trunk limb nerve; *n.visc.* visceral nerve.

plane as in the photograph (Plate XLI, fig. 2), but always inside the neurilemma sheath it joins one or other of the laterally placed nerves supplying the lateral components of the nauplius eye (Fig. 13). The latter nerves form the two outside members of the row of four. They are very massive and soon swell up into the large lateral ganglia of the nauplius eye. In between them a pair of small nerves arise which extend forwards along the median lower edge of the nauplius eye. They soon unite and run to the small frontal organ (Fig. 12). Lüders did not discover the small median nerve to the nauplius eye, and as a result mistakenly described the latter paired frontal organ nerve as a nauplius eye nerve.

At the sides of the brain, just in front of the anterior limit of the nervous mass inside the neurilemma, the nerves to the paired eyes make their exit. These were figured by Lüders as long nerves extending to the bladderlike structures which project from the body wall and represent the vestigial paired eyes (Plate XXXIX, fig. 2). Actually, however, I think the nerves are quite short and it is the paired eye itself which has become stretched and extends into the body as a narrow conical structure which then joins the nerve just outside the nerve ring (Plate XL, fig. 1). The peculiar pattern which is to be seen in the eye itself extends down the narrowing cone well into the body. In addition to this there is a sharp staining difference which supports this view. The nerve, as it leaves the ring, stains orange in Mallory, but at the small swelling (Fig. 13) which I take to represent the junction between the nerve and the eye, the staining reaction changes to blue.

Behind the paired eye nerve is a small nerve which represents the first of the shell nerves. It extends round the sides of the nauplius eye into the valves and spreads out over the most anterior part of the valves. I call it the shell nerve I. Soon after leaving the central nerve ring it is joined to a plexus of nerves running through the antenna. It is figured but not mentioned by Lüders.

The antennulary nerves arise from the ventral side of the nerve ring as in the case of *Doloria*. They enter the antennule almost directly and swell into the large antennulary basal ganglia.

The antennal nerve divides into three as it leaves the nerve ring. The middle portion is by far the largest and represents the large nerve that I described in *Doloria* as containing the giant fibres which enervated the powerful muscles in the base of the antenna. It can be traced in *Gigantocypris* to a very complicated and double basal ganglion but, as I shall repeat later, it contains no giant fibres. The other two branches of the antennal nerve enervate sundry small muscles in the base of the limb. The anterior nerve receives the connexion with the shell nerve I, which I have mentioned above, but a more important connexion is with the posterior antennary nerve. These two branches are connected together through a plexus of nerves ending on the wall of the end sac of the antennary gland (Fig. 13).

A short distance behind the antennal nerve is an isolated nerve (Fig. 11) figured by Lüders who states (1909, p. 37) that its distribution could not be accurately followed. It is the second nerve supplying part of the valves. It extends laterally close underneath the antennolabral apodeme through the isthmus and into the thickness of the shell where it divides at once into two main branches, one running dorsally and the other ventrally. The dorsal branch gives off a group of very small nerves which form a plexus among the strands of the adductor muscle. These join up by a single nerve with the more posterior shell nerve III.

Behind the shell nerve II is a group of five nerves which may be called the mandibular group. Of these, one makes its exit definitely on the ventral side of the nerve ring and is the main origin of the labral visceral system (Fig. 11). This will be dealt with later. Another nerve, not so ventral in origin as the last, and at the posterior margin of the group, runs directly into the mandible where it enters the large mandibular basal ganglion. It may be termed the mandibular sensory nerve. Of the remaining three nerves two are relatively small and run direct to the musculature of the mandible. They can be traced with certainty to their termination on the muscles of the mandible. They constitute the anterior and posterior mandibular motor nerves. The last member of the group is large and makes its exit more dorsally than the remainder. Soon after leaving the nerve ring it divides into two separate branches (Figs. 11, 14). Of these the lower is the larger branch and is the shell nerve III. Like the second of this series it divides into dorsally and ventrally running branches which ramify over the surface of the valves. The upper branch is the nerve to the adductor muscle. I have traced it on to the final nerve endings on the separate strands of the adductor muscle (Fig. 14).

The maxillulary group of nerves behind the mandibular illustrates well the variation that occurs among the origins of these nerves. In Fig. 13 it will be seen that on one side the group consists of three distinct nerves, while on the other there are only two. This type of variation was found throughout the nerve ring but more particularly at the hinder end. The most dorsal member of this group (Fig. 11) is really a double nerve consisting of an anterior cardiac nerve together with a shell nerve IV. I shall deal with this nerve later. The remainder of this group supplies the maxillule.

The main maxillary roots are two in number on either side. One, which represents a mixed nerve, in addition to supplying the main maxillary muscles, supplies the musculature of the vibratory plate and arises mid-way between the maxillulary group and the long trunk which marks the beginning of the ventral chain. The second arises close alongside this trunk and is a sensory branch swelling up almost immediately into a large basal ganglion (Plate XL, fig. 7). There is a very small nerve which arises from the dorsal side of the trunk just before it swells up into the terminal swelling of the chain (Fig. 11). This supplies a large muscle which attaches anteriorly to the front edge of the maxilla and posteriorly to the adductor muscle. I described this nerve in *Doloria*, but in this form it is as large as the other two maxillary nerves.

The nerves to the first trunk limb arise from the ventral side of the stalks of the ventral chain immediately below the small third maxillary nerves (Figs. 11, 13). They enlarge almost at once to form the basal ganglion of the limb.

Behind the nerves to the first trunk limb the nerves become very irregular in their origin (Fig. 13). The next following nerve is connected with the heart and dorsal body wall, which I deal with later. It is figured by Lüders and erroneously described as supplying the muscles of the vibratory plate of the maxilla. Close behind this again is the double root of a long nerve which runs to the second trunk limb and ends in a relatively small basal ganglion near its base. Behind this the nerves appear to vary considerably and run to the various muscles connected with the caudal furca. I have not followed them in detail.

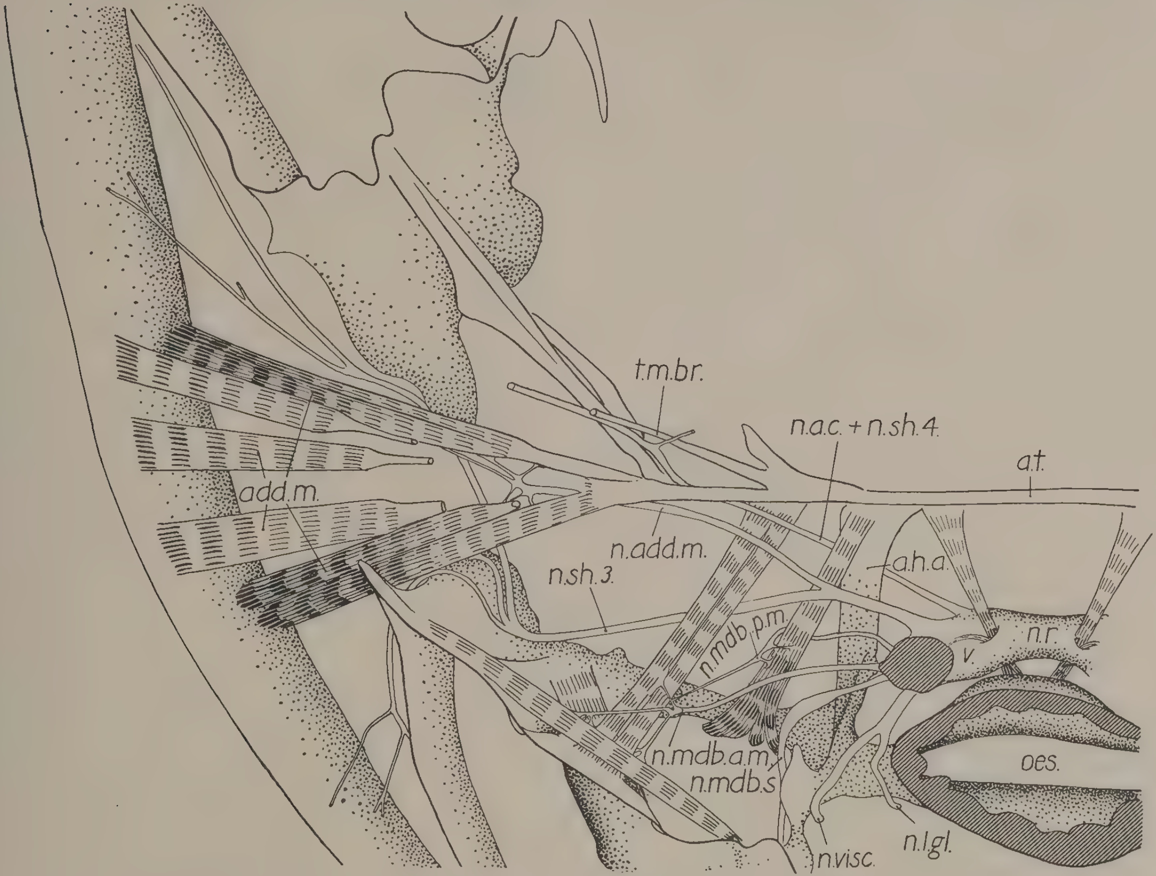

Fig. 14. Reconstruction from a series transverse to the nerve ring of a slice in the region of the mandibular outflow to show the nerve supply to the adductor muscle. *add.m.* adductor muscle; *a.h.a.* anterior hypostomal apodeme; *a.t.* adductor tendon; *n.a.c.* anterior cardiac nerve; *n.add.m.* nerve to adductor muscle; *n.l.gl.* branch of visceral nerve leading to labral glands; *n.mdb.a.m.* anterior motor mandibular nerve; *n.mdb.p.m.* posterior motor mandibular nerve; *n.mdb.s.* sensory mandibular nerve leading to mandibular basal ganglion; *n.r.* hinder (tritocerebral) region of nerve ring; *n.sh.* shell nerve; *n.visc.* visceral nerve; *oes.* oesophagus; *t.m.b.r.* tendon of dorsoventral body retractor; *v.* muscle controlling valve in supraneural blood vessel.

The ventral chain system consists of two parallel trunks which swell up in places and make various cross connexions. Lüders (1909, p. 138) states that there are four commissural connexions and these indicate that this chain system is primitive and represents the type of nervous system only found in the Crustacea among certain

Branchiopoda (Fig. 13 and Plate XL, figs. 7, 8). Actually only the second and third cross connexions are commissural. The first cross connexion results from the two trunks swelling up and touching in the middle line. The fourth is a peculiar cross connexion on which is situated a median ganglion. From this ganglion a minute nerve is given off which runs forward and has been termed by Lüders the sympathetic system. I can give no explanation of the existence of this ganglion. It is obvious in the photograph (Plate XLI, fig. 2) and also occurred in the specimen from which the nerve ring was reconstructed. In the second specimen from which the ventral chain system was drawn I am equally certain however that this ganglion was absent. There is really, therefore, only one commissural connexion which is divided into two by a vacuity. In addition, the nerves to the limbs which are given off from the ventral chain system bear no definite relation to the cross connexions. It would appear therefore more probable that the relatively long ventral chain is merely a secondary effect, another result of the enlargement of the body.

CARDIAC NERVOUS SYSTEM

I have been able to follow the nervous connexion between the heart and pericardium and the central nervous system, first from sections and subsequently, to confirm this, by actual dissection.

The heart itself possesses one large neurone situated on the inner surface of the roof at the convergence of the two ostia (Figs. 10, 15). This sends out two axons laterally which extend close against the wall to a point just dorsal to the hepatic valve where a branch runs downward to the floor of the heart, while another branch penetrates the wall and makes its exit into the pericardium. There are other branches from this single neurone which are shown in Fig. 10. I have not, however, been able to investigate the complete cardiac system with certainty. The axons do not stain and are only visible by their peculiar meandering arrangement. It is quite possible that the latter effect would vary with the varying degree of contraction or relaxation of the cardiac muscles on fixation. It is not surprising therefore that these nerves appear to vary considerably. What I have described above and figured, however, appear to be constant in all my preparations.

The cardiac nerve, on leaving the heart, is thus a single axon and is naturally very difficult to follow in sections, not only because of its size but because it does not readily stain. With the method of projection reconstruction, however, I found it possible to follow this minute nerve through all the sections to its central connexion. I then attempted to find it in dissection and found that this also was possible by using a very dark background and a powerful beam of light focussed almost horizontally across the dissection. The light reflected off the axon was sufficient to enable me to trace it and finally to dissect out the isolated nerve. As the nerve approaches the central nerve ring it joins up with other branches and becomes more easily manipulated.

On emerging from the heart (Fig. 15) it curves upwards and gives off a side branch to the first dorsal longitudinal muscle (Fig. 9). It then loops over the group of the second to fifth and then runs downwards with the outer group of sixth to eighth dorsal longitudinal muscles in the afferent channel of the pericardium. Just below the point where the three outer muscles twist over each other (p. 215) the nerve divides into two branches, one continuing downwards as the posterior cardiac nerve in the afferent channel and the other passing through the pericardial floor close against its anterior attachment to the body wall. The latter I call the anterior cardiac nerve. It runs downwards towards the adductor tendon and receives a branch from the shell near the bottom of the isthmus, the fourth shell nerve. It then runs as the combined anterior cardiac + shell nerve IV down the tendon of the dorso-ventral body retractor muscle (Figs. 6, 14) to loop under the adductor tendon and enter the nerve ring on the dorsal side of the maxillulary group (Fig. 11). The anterior cardiac portion, as it passes downwards, gives off small branches which can be traced to their nerve endings on muscles 4, 5, 11 and 10 (Fig. 9).

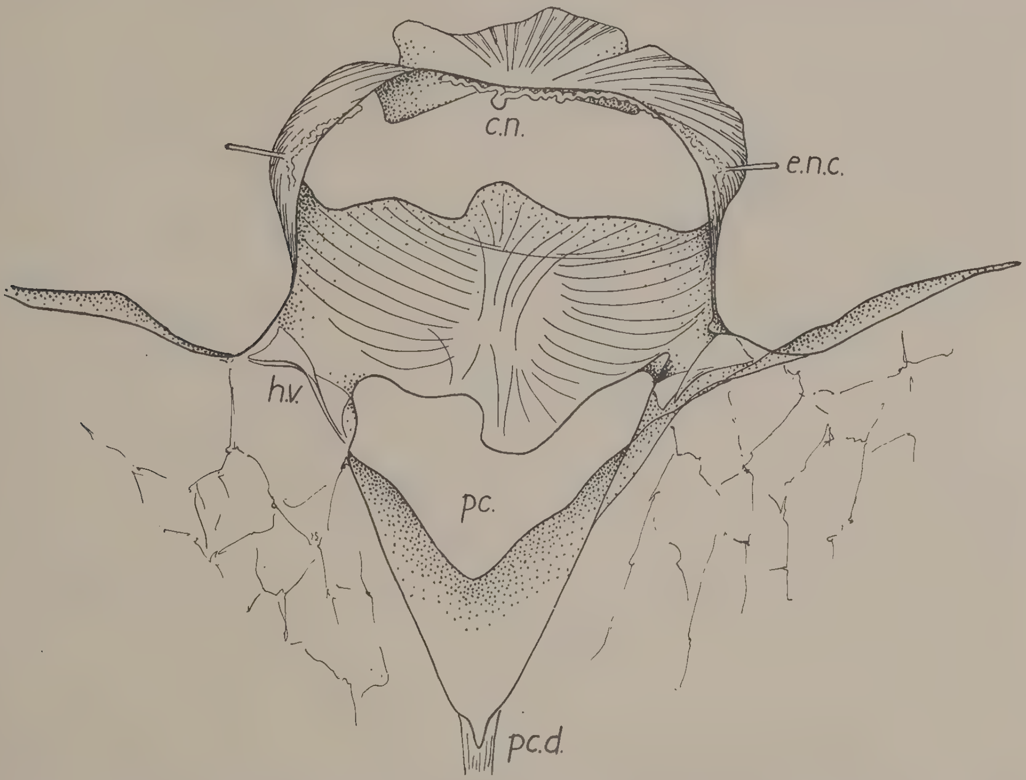

Fig. 15. Drawing of a thick section passing through the single cardiac neurone and the pair of hepatic valves. *c.n.* cardiac neurone; *e.n.c.* efferent cardiac nerve; *h.v.* hepatic valves; *pc.* pericardium; *pc.d.* pericardial dilator.

The posterior cardiac nerve continues down the afferent channel to a point near the lower ends of the outer dorsal longitudinal muscles. Here it receives a large nerve from the dorsal body wall—the pericardiac nerve. This I have traced spreading out over the body wall giving off branches which enervate both the dorsal longitudinal and the circular muscles (Fig. 9). The combined posterior cardiac and pericardiac nerve then continues downwards to enter the swelling on the ventral chain that I have already described (Fig. 13).

The main interest of this cardiac system is the correspondence between it and the supposed method of functioning of the body musculature which I have deduced from purely morphological grounds (pp. 215–216).

There are two antagonistic sets of muscles which may be termed the protractor and the retractor systems of the body. The protractor system consists of the dorsal longitudinal and circular system of the dorsal body wall of the trunk. By their contraction, as I have explained (p. 195), the anterior body centring round the adductor muscle will be protruded forwards. The retractor system consists mainly of muscle 10 which, since it is attached directly to the adductor tendon, will pull back the anterior body. In addition, muscles 4, 5 and 11 will retract the massive second antennae. Obviously the interaction of these two sets of muscles not only brings about the movement of the body relative to the shell, but as a resultant controls the internal body pressure, that is the blood pressure. Further, in this, as in all forms, the efficient working of the heart depends on a nicely balanced blood pressure. Now in the heart itself there is the single cardiac neurone which is connected through the cardiac nerve directly to the nerves controlling, on the one hand, the protractor, on the other the retractor system of muscles. This suggests at once that the single cardiac neurone is the controlling centre regulating the balanced action of these two sets of muscles.

Further, for the heart beat a continual supply of blood is necessary, and this enters the pericardium mainly via the efferent canal. This canal is kept open by the contraction of the bowed muscles, dorsal longitudinal nos. 6, 7 and 8 (p. 215) and, in correspondence with this, the posterior cardiac nerve can be traced to nerve endings on these muscles (Fig. 9).

BASAL GANGLION SYSTEM

The series of basal ganglia which I described in *Doloria* (Cannon, 1931, p. 468) as occurring in the base of each limb is present also in *Gigantocypris* (Plate XLI, fig. 5). The ganglia are large—so large that it is possible to dissect them out of the limbs, with the exception of the last trunk limb. Here the ganglion is so small that it was only with difficulty that it was discovered as an elongated accumulation of nerve cells near the base of the limb. Apart from this the basal ganglion system calls for no comments.

VISCERAL SYSTEM

The visceral system is extremely well developed. It is based on the same plan as that of *Doloria*, but in addition there is a new system connected with the aorta.

The labral loop bearing the medial labral ganglion is present (Figs. 11, 16). Its two ends emerge from the nerve ring in the same position as in *Doloria*, that is, in the mandibular region (see p. 226), but there are no marked mandibular swellings.

They soon give off branches to the labral glands (Fig. 14). From the labral ganglion a small nerve runs downwards towards the tip of the labrum (Figs. 11, 12). It supplies various dilator muscles of the mouth region and then ends in a small distal labral ganglion. Dorsally the labral ganglion sends off two nerves. Of these the anterior runs up to the ganglion which in *Doloria* I have termed the stomach ganglion. I call it the labral connective. In *Doloria* this nerve passes through the frontal foramen of the brain (Cannon, 1931, p. 471). In *Gigantocypris* there is no such foramen, but in the homologous position the nerve sends forwards a small twisted median nerve, the aortic connective, which joins directly the hinder wall of the brain (Fig. 12). It is possible that this connective is also present in *Doloria* but that I could not find it on account of its size.

From Fig. 12 it will be seen that the upper part of the labral connective runs close underneath what may be termed the floor of the aorta, that is, the lower median wall where the aorta bifurcates immediately behind the brain. Just at the junction where the aortic connective emerges from the labral connective a nerve is given off which immediately penetrates the aortic floor and branches into a plexus which spreads over the latter. The terminations of this plexus can be seen with certainty ending against the flattened nuclei in the neighbouring aortic walls.

The labral connective shows a series of at least three swellings. Between the upper two a branch

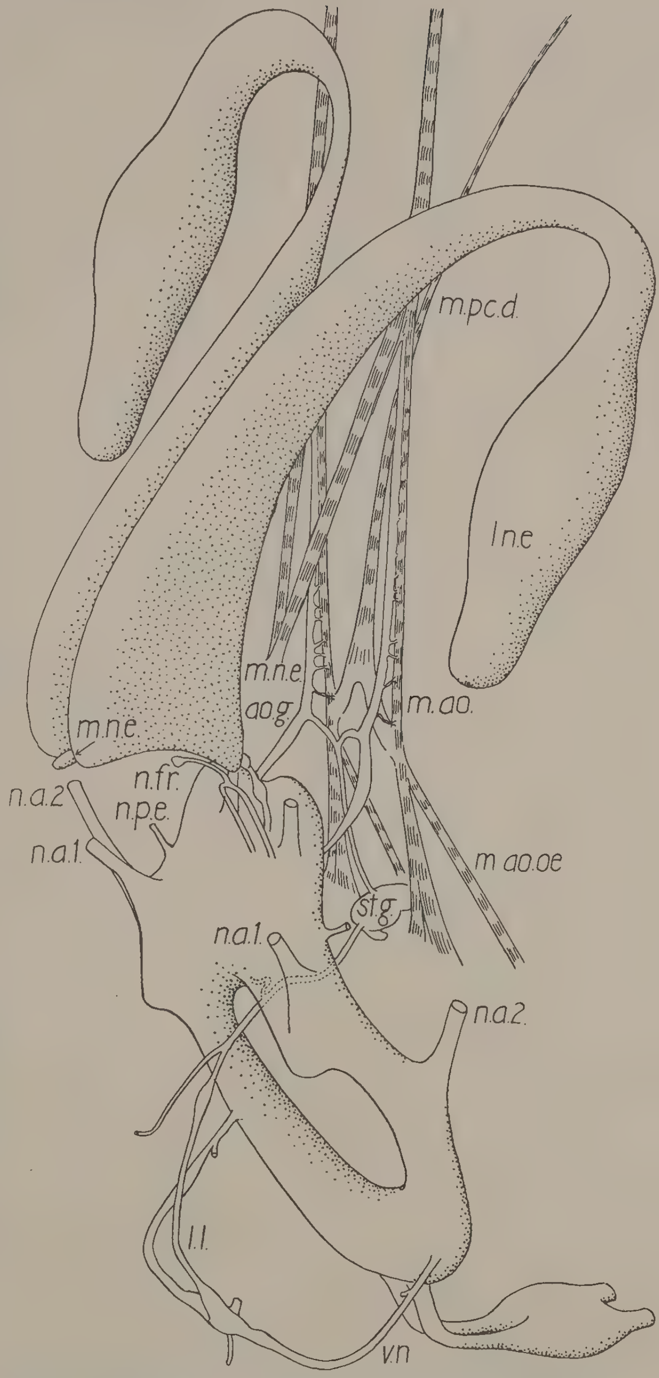

Fig. 16. Oblique view of nervous system and ganglia of nauplius eye, based on an isometric projection, to show the extent and arrangement of visceral nervous system. All nerves behind the antennal have been omitted. *ao.g.* aortic ganglion; *l.l.* labral loop of visceral system; *l.n.e.* ganglion of lateral component of nauplius eye; *m.ao.* aortic muscle; *m.ao.oe.* aortic-oesophageal muscle; *m.pc.d.* pericardial dilator; *m.n.e.* ganglion of median component of nauplius eye; *n.a.1*, antennulary nerve; *n.a.2*, antennal nerve; *n.fr.* nerve to frontal organ; *n.p.e.* nerve to paired eye; *st.g.* stomach ganglion; *v.n.* visceral nerve as it emerges from nerve ring.

runs forward to end on a levator muscle of the labrum. In a similar position in *Doloria* I described a small frontal ganglion, but this is not present in *Gigantocypris*.

The posterior nerve running upwards from the labral ganglion is a thick nerve which immediately penetrates underneath the circular muscles of the oesophagus. This forms a branching system similar to, but of a different pattern from that which I described for *Doloria*. In the latter form it originates from two outgrowths of the labral loop. In *Gigantocypris* it commences as a single nerve which then divides immediately it has penetrated the layer of circular muscles. The two branches so formed run up the sides of the oesophagus and connect with the stomach ganglion. They give off various branches, one of which from each side extends inwards to form a median nerve which ends before reaching as far as the stomach ganglion. This oesophageal plexus is thus similar to that of *Doloria*, but in *Gigantocypris* it was found possible to isolate it from its overlying musculature and to study it as a permanent stained preparation.

The stomach ganglion occupies the same position as in *Doloria*, that is, the bay between the aortic oesophageal muscles (Figs. 11, 12). It gives off a number of major branches. Two of these have been mentioned, the labral connective and the branch penetrating the circular muscles to bifurcate into the oesophageal plexus. Laterally it gives off branches which connect up with a plexus of nerve cells supplying the dilator muscles of the oesophagus. This plexus has not been inserted in any of the figures because, while it does concentrate into two main tracts running down the sides of the oesophagus but outside the circular muscles, it would be misleading to figure it in the same way as the definite connectives which have already been described. It is really a pair of chains of stellate nerve cells (Plate XLI, fig. 4) which are connected throughout the length with all the various dilator muscles. Ventro-posteriorly the chain on either side makes a very definite connexion with the nerve ring in the tritocerebral region, that is, at the level of the mandibular outflow of nerves.

From this anatomical description I think it can be deduced that among other functions the stomach ganglion controls the peristaltic movement up the oesophagus. The anterior outflow which lies underneath the circular muscles I take as the motor supply to these muscles, that is, the constrictor system, although I have not been able to see any actual nerve ending on them. The postero-lateral chain of nerve cells is the motor supply to the dilator system. It is significant that this latter group of nerve cells connects with the nerve ring in the mandibular region. I have not, however, been able to find any internal connexion to the mandibular nucleus.

Anteriorly the stomach ganglion gives off a median nerve which, after a short distance, penetrates the floor of the aorta and enters the latter (Fig. 12). It extends up the aorta to about the level of the aortic tendon, that is, at the base of the aortic and pericardial dilator muscles. Here it bifurcates into two short branches (Fig. 16) which extend laterally to two elongated aortic ganglia. The latter extend both up and down the aorta. Upwards they stretch close against the aortic muscles to a point where this muscle meets the nauplius eye muscle. At this point they send numerous attenuated connexions to a similar ganglion extending some distance down the latter muscle (Fig. 10) and I am assuming that this is really one ganglion on either side serving the two muscles. Down the aorta the ganglia extend on each side as elongated structures narrowing to a point where they penetrate the aortic floor and immediately join the dorsal surface of the brain (Figs. 12, 16). Throughout the whole ganglion numerous connexions are being made with the muscles.

This aortic ganglion system is a new development in *Gigantocypris*. In *Doloria* I figured a median nerve from the stomach ganglion which I stated (p. 471) "can be traced to the aortic roof and the pericardial dilator". I could not trace it further than the aortic tendon and hence deduced that it supplied the two muscles extending upwards from this. I now think that it probably has no connexion with the pericardial dilator and serves only the aortic muscles. In *Gigantocypris* it connects through the aortic ganglia with the aortic muscles from their origin at the aortic tendon upwards (Fig. 16). It however has no connexion with the pericardial dilator. The latter appears to be without a separate nerve supply.

The morphological facts suggest strongly that the pericardial dilator is an independent effector organ. Although attached to the same tendon ventrally as the aortic muscle, I pointed out that in *Doloria* the pericardial dilator must work in opposition to the latter muscle (1931, p. 459). This would fit in with the fact that while the latter has such a marked nerve supply the former has none. Further, the striations of the pericardial dilator are extremely simple. In fact, I call it a muscle merely because it shows alternating bands of staining and non-staining substance. But these bands are not at all sharply marked from each other. I have repeatedly remarked that in the Crustacean body it is possible to find all stages of the transition from connective tissue cells showing longitudinal striations to typical striated muscles, the stages, in fact, that are exhibited in the embryology of ordinary striped muscles (Cannon, 1926, p. 414). The pericardial dilator of *Gigantocypris* represents a morphological level about the middle of this series. At the beginning of the series it would not be expected that the connective tissue cells would of necessity have their own motor supply. At the other end of the series one would naturally expect a direct nerve supply. The pericardial dilator, I suggest, represents a stage in the evolution of a contractile system before this direct nervous control appeared.

There is, of course, the possibility that the nerve supply to this muscle is extremely fine and cannot be demonstrated by the methods I have used. This certainly may be so, but a point against such an assumption is the fact that it is possible to trace the nerve supply of practically every muscle of the body, and always the nerve ending is the same. It is a little pillar of protoplasm which spreads out on the effector organ and is of the size indicated in the text figures, that is, of a size easy to see and in fact difficult to overlook.

INTERNAL STRUCTURE

As regards the internal structure of the central nervous system, I am describing only those points which appear significant in comparison with the account which I gave of the nervous system of *Doloria* (1931, p. 472).

In *Doloria* the nucleus of the nauplius eye nerves consist of three equal ovoid glomerular masses associated with three equal small nerves. In *Gigantocypris* the nucleus consists of two large glomerular masses, one on either side of the median plane. This is what might be expected from the structure of the eye in which the lateral components are enormous compared with the median and also from the fact that the small nerve from the median portion always joins with one or other of the much larger lateral nerves.

From the nucleus of the nauplius eye two giant fibres run back to the level of the protocerebral bridge. In *Gigantocypris* the brain is very much compressed antero-posteriorly so that the latter structure lies close against the more posterior central body. In this region the giant fibres appear to bifurcate and extend laterally. The left branches of each join and extend outwards to the nucleus of the paired eye of the left side. The right branches behave in a corresponding manner. This nucleus appears as a simple spherical glomerular mass close against the sides of the protocerebral bridge. It does not show the distinctions into lamina and medulla as in *Doloria*, neither is there a large connective mass of nerve fibres between it and the central body.

The nauplius eye is thus linked directly by a chiasmatic giant fibre system to the nuclei of the paired eye. This is important as the paired eyes are certainly not the usual type of ocular organ. They may even be described as rudimentary. In more typical Cypridinids the paired eyes are normal and function normally, and the optic centres are connected through the system of tracts associated with the central body with the other important centres of the nervous system. In *Gigantocypris*, although the paired eyes have ceased to function in the normal manner and the predominant organ is now the nauplius eye, the latter has continued to use the association or distribution centre of the paired eyes for the co-ordination of its activities.

The most important point about the internal anatomy of the nervous system is that, apart from the giant fibres I have just described, there appear to be no others in the whole system. The significance of this is that it throws further light on the meaning of a giant fibre system generally.

In a recent paper on the functioning of the giant fibres of the squid, Young (1938*a*) has pointed out that the mantle has a double nerve supply—a system of relatively small fibres which are presumably used in the ordinary movement of respiration and a giant fibre system to be used for rapid movement. In another paper (1938*b*) he has drawn attention to the fact that the Octopod Cephalopods having developed the use of their arms for walking have given up the more rapid contractions of the mantle such as occur in the squid and at the same time have lost their giant fibre system. This all fits in with the views expressed by Miss Lowe (1935) in her monograph on the anatomy of *Calanus*. In this paper she describes the giant fibre system and shows that in addition to acting as a co-ordinating system within the central nervous system it supplies all *and only* those muscles which are used in the escape reaction, previously analysed cinematographically by Storch (1929).

Now in *Doloria* I showed that the giant fibres outside the central nervous system only supply the massive muscles of the second antennae and it is these muscles that are used by a normal Cypridinid in the excessively rapid escape reaction that it shows when disturbed. In *Gigantocypris* there are no giant fibres extending outside to the muscles of the antennae—or in fact anywhere else—but then *Gigantocypris* can have no escape reaction. Its size and shape preclude that. The movement of an ordinary Cypridinid in swimming away from a disturbance is as rapid, if not more so, than that of a Copepod. Clearly, as I have pointed out previously, the body of a *Gigantocypris* could not possibly move itself through the water with any speed. Hence the absence of the giant fibre system.

These observations support very strongly what a cursory survey of the animal kingdom shows, namely, that all those animals where a giant fibre system is known to be present show a definite escape reaction. The earthworm, tubicolous worms and the crayfish are three obvious examples. A giant fibre system, therefore, appears to be a nervous mechanism which has evolved to co-ordinate escape movements.

EXCRETORY ORGANS

The segmental excretory organs of *Gigantocypris* are antennal glands (Cannon, 1931, p. 478). They have the same gross anatomy as those of *Doloria*, each consisting of a simple end sac, an efferent duct and a "sphincter" guarding the entrance into this duct from the end sac.

The whole gland is situated in a posterior thin walled bulge on the basis of the antenna. The duct opens as in *Doloria* on the outer side at the junction of this thin walled lobe and the more anterior thick walled muscular part. It consists of two distinct portions—distally a tubular invagination of thickened ectoderm and proximally an intracellular duct formed by three cells only. That there are only three cells in this latter part of the duct was established from the sections of an embryo which has been mentioned previously. Here the developing duct had the same appearance as in other intracellular ducts that I have studied. The width of the lumen was approximately the same as the thickness of its walls and the nuclei were at least twice the volume of the surrounding nuclei. In the adult, however, the cells appear to have the actual shape of an agricultural drain-pipe—that is of a relatively thin walled hollow cylinder. The nucleus of the individual cells bulges *into* the lumen and not to the outside as might be expected (Fig. 17*b*).

These duct cells lie close against the lateral ectoderm of the basis of the antenna and are connected to the ectoderm by ordinary connective strands (Fig. 17*b*). On the inner surface, however, they are covered by a simple epithelium of exceedingly thick cells which appear glandular. The proportion between these cells and the duct cells proper is such that at first sight it looks as though the duct cells merely form the peripheral layer of the gland cells. From the section seen in Fig. 17*b*, however, it is clear that the duct cells are quite distinct from the overlying gland cells. The latter, if they are in fact glandular, pass their secretion outwards into the cavity of the limb and not into the duct of the gland.

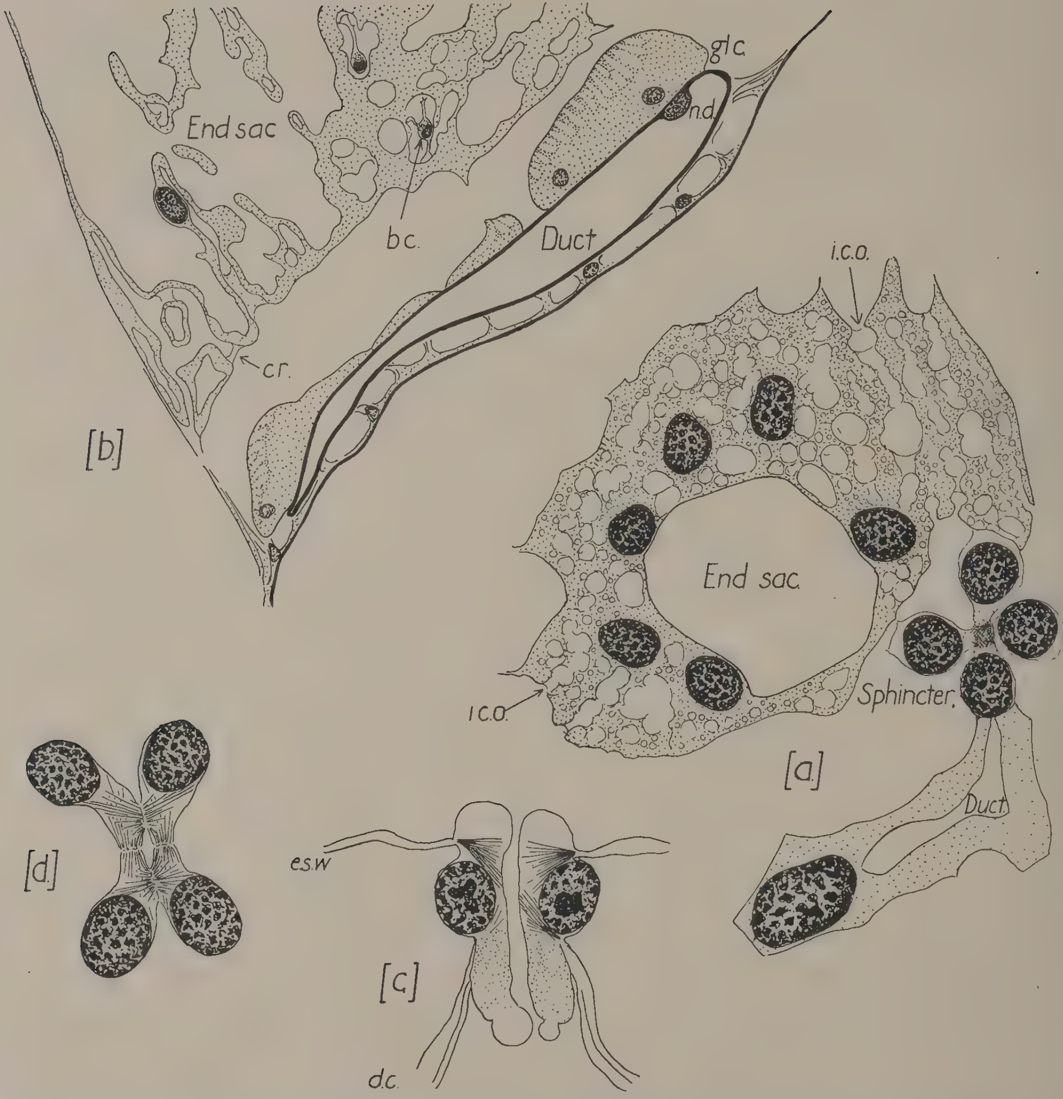

Fig. 17. *a*. Thin section through antennal gland of embryo showing thick walled intracellular duct, four cells forming sphincter and end sac with thick walls penetrated by intracellular cavities. *b*. Thin section through antennal gland of adult. The end sac wall has become much folded and in its crypts can be seen blood cells with peculiar amoeboid processes. The duct is very thin walled—the wall is represented by the thick black line only—and is covered on its inner side by gland cells. *c*. Thin section through sphincter. *d*. Surface view of sphincter. *b.c.* blood cells; *cr.* crypts ramifying in end sac wall; *e.s.w.* wall of end sac; *gl.c.* gland cells; *i.c.o.* openings leading into intracellular crypts from the outer surface of the end sac epithelium.

The sphincter between end sac and duct is so similar in sections to that of *Doloria* that there can be no doubt that the constitution of the structure in the two forms is the same. In this case my tentative description of the valve in *Doloria* is certainly incorrect. In that form I suggested (1931, p. 478) that the number of cells in the sphincter valve was three and by comparing it with the antennal gland of *Chirocephalus* I implied that these three cells, and hence their contained myofibrils, were connected directly to the ectoderm. I have various series of thin sections of *Gigantocypris*, in one of which the antenna was so orientated that the section is accurately transverse to the valve. From these series there is no doubt whatever that the valve consists of four cells and that these cells are not in any way connected to the ectoderm. Their myofibril apparatus is contained entirely within themselves. Further, in the sections of embryos the sphincter shows as a group of four cells (Fig. 17*a*) and these form the junction between the developing sac and duct but are not otherwise connected to any cells.

This constitution of the sphincter is remarkable for in all previous descriptions of similar structures, when the number of cells constituting the sphincter has been stated, it has always been three (Vejdovsky, 1901). In one case, that of a Cyprid, I followed the embryology and showed that three ectodermal cells become intercalated between end sac and duct to form the sphincter (Cannon, 1925). Now in *Gigantocypris* we have a case of an apparently homologous structure in which the number of cells is definitely four, and there is no evidence to suggest that they have been connected to the ectoderm.

The real difficulty, however, is not to justify the homology of a sphincter of three cells with one of four cells, for, in the evolution of the larger *Gigantocypris* there is no reason why an additional cell should not have been added to the original sphincter. The difficulty is to explain how, if they are strictly homologous, the method of functioning of the one can have evolved into that of the other.

In *Chirocephalus* or *Cypris* the fibrils form a triangle whose three corners represent the attachment of the fibrils to the exoskeleton. The sides of the triangle are curved inwards. Obviously contraction of these fibrils will straighten out the sides of the triangle and this will open the sphincter.

In *Gigantocypris* the primordium of the sphincter consists of four pear-shaped cells with their narrow ends surrounding a tubular space (Fig. 17*a*). In the adult the same arrangement of cells is to be seen but the fibrils can now be distinguished. They are arranged in two distinct sets—one set against the wall of the end sac whose fibrils run on the whole at right angles to those of the other set which is against the commencement of the duct (Fig. 17*d*). On the inner surface of the cells, that is close against the lumen of the duct, fibrils from one set run down to meet the other (Fig. 17*c*). In this way the fibrils which together surround the duct and form the so-called sphincter are arranged along four sides of a tetrahedron. Contraction of these fibrils alone would presumably close the sphincter but the whole system taken together is too complicated to allow of any useful suggestion as to its method of functioning. At the same time it is clear that it cannot work in the simple manner of the triangular sphincter of other forms, and further it is difficult to see how an intrinsic tetrahedral system of fibrils can have evolved from an extrinsic triangular system. This anomaly is parallel to the case which we (Cannon and Manton, 1927) pointed out in connexion with the maxillary glands of *Chirocephalus* and of *Cypris*. These segmental excretory organs occurring in the same segment of two related forms would normally be classed as homologous, and yet in the one, *Chirocephalus*, the duct and sphincter are both mesodermal while in the other, *Cypris*, they are both ectodermal.

The sphincter cells project into both end sac and duct, but to a much greater extent into the latter. This seems to be a constant feature in sphincters of this type for Vejdovsky (1901) describes such a state of affairs in *Gammarus*, while we (Cannon and Manton, 1927) figured it for *Anaspides* and certain Euphausiacea and Penaeids. Vejdovsky, however, distinguishes between valve cells, which are those projecting into the lumen, and separate external muscular cells. There is no such distinction in *Gigantocypris* and I have not yet discovered a Crustacean valve in which these two separate elements occur.

In *Gigantocypris* the cells protrude as four elongated masses of glandular cytoplasm into the duct (Fig. 17*c*). In each mass, at the sphincter end, are droplets of secretion. Towards the distal ends these become larger and at the same time less distinct until at the tips of the cells large drops, presumably of this section, appear to be shed into the cavity of the duct.

The interest in the end sac wall naturally lies in the manner by which *Gigantocypris* has compensated its excretory surface proportional to its enormously increased volume. At first sight this appears to have been brought about by the development of a labyrinthine structure. Sections of the adult gland certainly give this appearance. Sections of the embryo, however, show that there is something more. A labyrinth may be considered as derived from a sac which, by the rich development of partitions and trabeculae from its walls, has been converted into a spongy mass traversed by a complex system of "canals" (Calman, 1909, p. 285). This has certainly taken place in *Gigantocypris* but previous to this development, which can be considered as a folding of the surface of the end sac, another has taken place which is a pitting of the outer surface of the end sac epithelium. It is this outer surface which represents the effective excretory surface of the end sac. By developing folds in the epithelium or crypts into the outer surface the excretory surface will be increased. In *Gigantocypris* both these processes have taken place (Plate XLI, fig. 6).

In the embryo the wall is a simple but very thick epithelium. It is probably syncitial and the nuclei are all arranged against the inner surface (Fig. 17*a*). The latter is continuous and small so that it forms, as would be expected, a complete wall around the cavity of the end sac. The outer surface of the epithelium, however, is pierced by numerous holes and these lead into crypts which extend into a ramifying system of vacuolar spaces reaching as far as, but not breaking through the inner surface. The labyrinthine structure, as far as the outer surface of the end sac wall is concerned, is thus primarily due to the development of an intracellular system of crypts. That of the inner surface is due to an intercellular system of folds. Whether or not the outer surface also subsequently develops folds it is impossible to say.

The lacunae of the labyrinth can be seen to contain considerable numbers of blood cells. Blood cells, while they are circulating, have the normal appearance of approximately spherical bodies. They usually contain a group of vacuoles at one side of the nucleus and often a small pseudopodium. Where they adhere to connective tissue fibrils this pseudopodium may become very prominent. In the labyrinth, however, the pseudopodium takes on remarkable shapes. All stages can be found from a normal cell, through forms in which the pseudopodium has extended out into a filiform structure, to cells showing a complicated branching system of outgrowths. These outgrowths may have enlargements at the end and it is by these that the cell is moored to the wall of the lacuna. Where the pseudopodia end in a branching system (Fig. 17*b*) I deduce that these are still growing outwards and have not yet made contact with the labyrinth wall.

There is a peculiar tissue, which I have called nephrocyte tissue, situated just below the lateral parts of the adductor muscle. From its proximity to the maxillary segment and from its appearance in sections (Plate XLI, fig. 7) I thought at first that it represented a maxillary gland. However, the apparent end sac which is so obvious in the photograph is not, in fact, a sac as its cavity is completely open posteriorly. The walls are made up of enormous stellate branching cells, some of which project from the surface and ramify particularly anteriorly. One of these can be seen very clearly projecting downwards in the photograph. Its nucleus can also be seen, and this is typical of the tissue. The nuclei are very swollen and appear to consist of an irregular inner staining mass surrounded by a clear space. They have all the appearance of degenerating nuclei, but this seems improbable as they all appear to be in the same stage. The cytoplasm stains markedly with chlorazol black and is uniformly vacuolated throughout. The vacuoles all appear to be of approximately the same size and project from the surface so that the latter has a very marked warty appearance.

In referring to this tissue as nephrocyte tissue I do not imply that there is any evidence that it is excretory in function, but merely that in a morphological sense it compares with the nephrocytes of other forms. These are usually associated with pericardium or else, as in Isopods, with the gills. In *Gigantocypris* the nephrocyte tissue occurs in the upper end of the maxillule where there is a globular appendage (Figs. 1, 3 and Plate XLI, fig. 5) which I consider a gill. It resembles the typical Branchiopod gill and is situated in the position where one could expect to find a gill. It also occurs in *Doloria* (Fig. 1) but here it is much more flat and is inconspicuous. It probably represents the missing epipodite of the maxillule. Hansen (1925, p. 68) said that he thought that a very thick plumose seta was a rudiment of the epipod. However, the gill that I describe here is so thin walled that in potash preparations such as Hansen used it would have been extremely difficult to make out with any certainty.

SUMMARY

All the Discovery specimens of *Gigantocypris* examined agreed with Skogsberg's species, *G. Mülleri*, which he described from material collected within the region of the Gulf stream.

The body of *Gigantocypris* is enclosed in an almost spherical shell provided with a ventral slit which represents the relatively short length over which the valves are not fused (Fig. 1). This bears two antennal notches through which the swimming antennae are extended (Plate XXXIX).

The body almost fills this enormous shell (Plate XXXIX, fig. 1) but it has not enlarged proportionately in all regions. Thus, while the dorso-posterior region between heart and caudal furca has enlarged to a hemisphere concentric with the shell, the limbs have neither enlarged to the same degree nor have they become spaced out. They remain closely packed together in a small antero-ventral region. Again, in the region between the anterior limbs and the heart, the nauplius eye has enlarged to such an extent as to occupy the whole of this region, while the paired eyes have shrunk to two small sacs and the frontal organ has dwindled to a minute tubercle on the lower face of the nauplius eye (Fig. 1 and Plate XLI, figs. 1, 3).

From its shape and size it can be deduced that *Gigantocypris* cannot move quickly through the water. Despite this, it feeds on active food such as giant sagitta, fast swimming copepods and young fish. It is suggested that it is a sedentary feeder grasping live prey by its mandibular palps which are extended through the antennal notches (Plate XXXIX, fig. 6).

The movement of the mouth and mouthparts towards the antennal notches is brought about by a hydrostatic system controlled by the criss-cross musculature of the flexible dorsal body wall of the trunk region. Contraction of this system of muscles forces the body fluid from the posterior into the anterior region of the body and so extends the mouth downwards. The reverse process is brought about by the dorso-ventral body retractors which are attached ventrally to the adductor tendon and dorso-laterally to the shell (Figs. 8, 9).

There is a nervous control which corresponds closely to this muscular system. It consists of a single neurone in the dorsal side of the heart which sends out two axons laterally that emerge from the heart on either side as a cardiac nerve. These extend downwards and then bifurcate into two branches. The posterior sends connexions to the circular and longitudinal muscles of the dorsal trunk region and then continues downwards to the posterior chain system. The anterior sends connexions to the dorso-ventral body retractor muscle and then continues downwards to the hinder part of the nerve ring (Fig. 9).

Further evidence is given from the study of an embryo that the circular muscles of the dorsal dome of the trunk region are of ectodermal origin (Fig. 2).

The body "floats" inside the spherical shell, being held in position by the adductor muscle. Since the valves of the shell cannot open, this appears to be the main function of the muscle in this genus. The limbs are connected to the adductor muscle by a powerful apodemal system in the centre of the body and laterally through an articulated sclerite system (Figs. 3, 4).

The articulated sclerite system is based on the same plan as that of *Doloria*. It has been described in more detail, and in addition the muscular system attached to it has been worked out (Fig. 5).

As in *Doloria*, the pericardial space consists of an anterior pericardium containing the heart and a posterior extending into the trunk region. The latter consists of a posterior lacunar space coextensive with the criss-cross of dorsal longitudinal and circular muscles and an antero-lateral tubular space which is an afferent canal leading from the general perivisceral cavity into the anterior pericardium (Figs. 7*a*, 7*b*, 9).

The arrangement of muscles which control the opening of the afferent canal is described together with their relationship to the skeletal system (Fig. 7*b*) and to the cardiac nervous control (Fig. 9).

The heart possesses an aortic and a pair of hepatic valves which, as in *Doloria*, are splits in a membrane bounded by muscular strands. The muscles controlling the hepatic valves are branches of the lateral subpericardial muscle. The muscles controlling the aortic valve continue ventrally into the pericardial dilator. Both these muscles depress the pericardial floor so that when blood is being sucked into the pericardium the hepatic and aortic valves remain closed. The pericardial dilator appears to have no nervous supply and may represent an independent effector organ (Figs. 9, 10).

The heart and aorta of *Gigantocypris* have enlarged out of all proportion to the other organs with the exception of the nauplius eye. The heart is, relative to that of *Doloria*, about fifty times as big.

The aorta sends off a minute labral artery medially and laterally an antennulary and antennal artery. Postero-laterally it bifurcates into two branches which extend along the dorsal surface of the lateral parts of the nerve ring and end at muscular valves. The latter are formed of oesophageal dilators which extend from the ventral ectoderm just behind the mouth and extend through the apertures in the tritocerebral region of the nerve ring (Figs. 11, 12).

The central nervous system consists of an anterior nerve ring and a posterior chain system. There is no evidence that the latter represents a primitive condition. The nerve ring is enclosed in a substantial but loosely fitting connective tissue sheath. This leaves a very marked space between the brain and its neurilemma (Fig. 13, Plate XL, fig. 1 and Plate XLI, fig. 2).

A basal ganglion system is present as in *Doloria*, but the ganglia are very large and more diffuse (Plate XLI, fig. 5).

All the nerves leaving the central nervous system have been traced to their nerve endings. In addition to the groups of segmental nerves supplying the limbs, there are the nerves to the nauplius eye which have three roots and to the frontal organ which has two roots. The rudimentary paired eyes have small roots. There are four separate paired shell nerves. There are anterior and posterior pericardial nerves mentioned above in this summary.

A well developed visceral system, based on the same plan as that of *Doloria*, is present and in addition there are very large visceral ganglia associated with the aorta (Figs. 10, 12).

The giant fibre system so conspicuous in *Doloria* does not appear to be present in *Gigantocypris*. It is suggested that this and other evidence indicates that a giant fibre system appears to be a nervous mechanism which has evolved to co-ordinate escape movements.

The walls of the end sac of the antennal gland are extremely thick and labyrinthine. In the intracellular cavities blood cells can be seen moored to the walls of peculiar amoeboid processes (Plate XLI, fig. 6).

The sphincter between end sac and duct consists of four cells containing an intrinsic system of fibres arranged in a tetrahedral plan. They are not connected to the ectoderm (Fig. 17).

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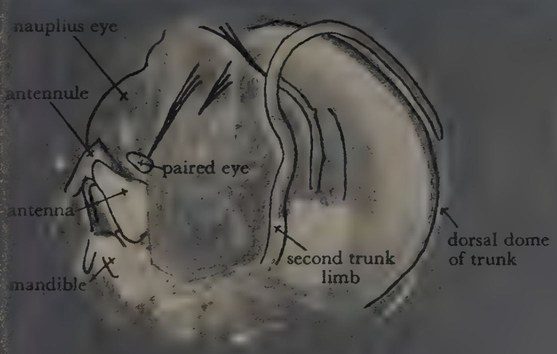
nauplius eye
antennule
paired eye
antenna
mandible
second trunk limb
dorsal dome of trunk

FIG. 1. Left-hand view of adult female from which the left valve has been removed with the exception of the isthmus covering the attachment of body to shell.

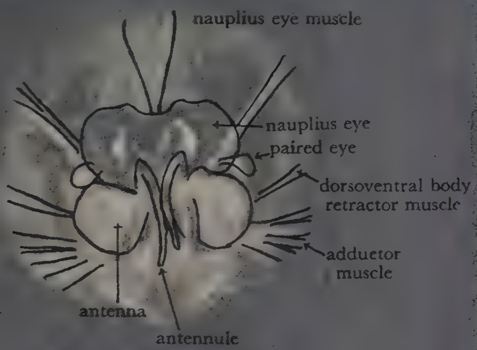
nauplius eye muscle
nauplius eye
paired eye
dorsoventral body retractor muscle
adductor muscle
antenna
antennule

FIG. 2. Anterior view of adult female from which the front part of the shell has been removed to expose the anterior limbs, adductor muscle, dorso-ventral body retractor muscle and heart region.

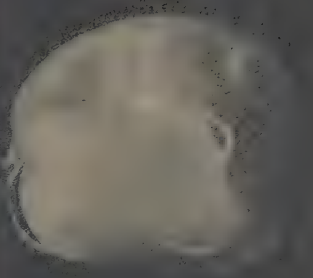

FIG. 3. Side view of adult female.

FIG. 4. Side view of adult male.

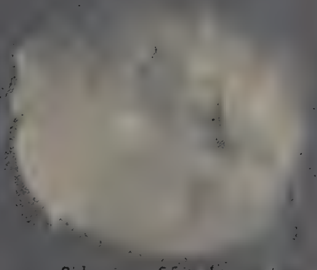

FIG. 5. Side view of female carrying embryos.

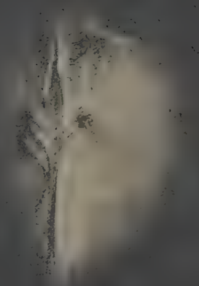

FIG. 6. Front view showing the anterior end of ventral slit.

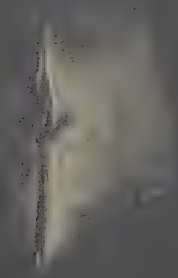

FIG. 7. Front view showing antennules projecting through anterior limit of ventral slit.

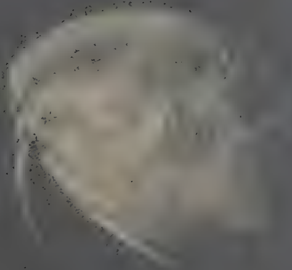

FIG. 8. Oblique front view showing antennae projecting through antennal notches.

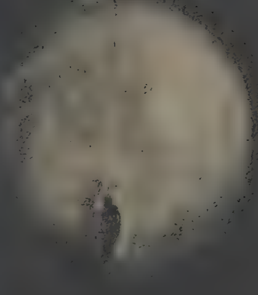

FIG. 9. Hind view of male, showing posterior opening and testis seen through the shell.

FIG. 10. Hind view of female carrying embryos.

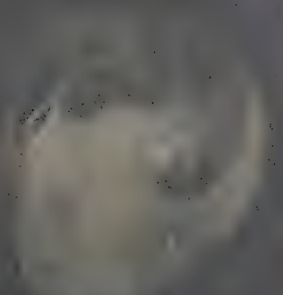

FIG. 11. Oblique hind view of adult male.

GIGANTOCYPRIS

The use of a lens is recommended for the examination of details in the plate

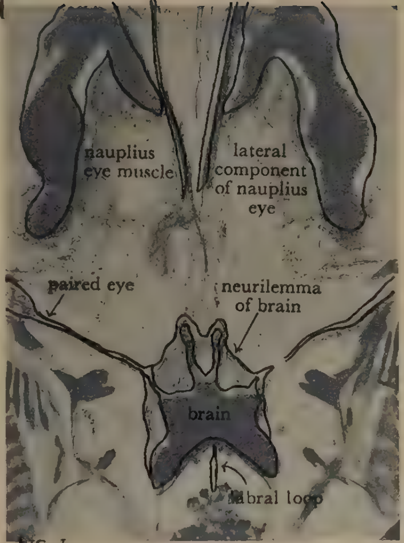
nauplius eye muscle
lateral component of nauplius eye
paired eye
neurilemma of brain
brain
labral loop

FIG. 1.

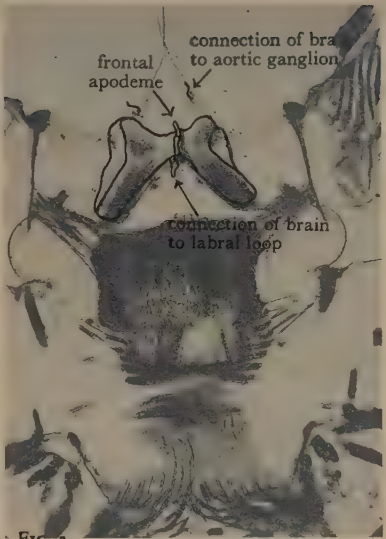
frontal apodeme
connection of bra
to aortic ganglion
connection of brain to labral loop

FIG. 2.

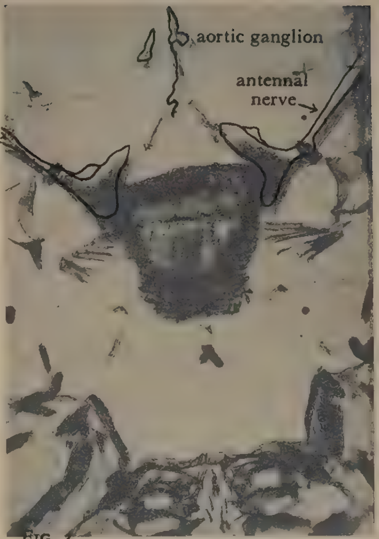
aortic ganglion
antennal nerve

FIG. 3.

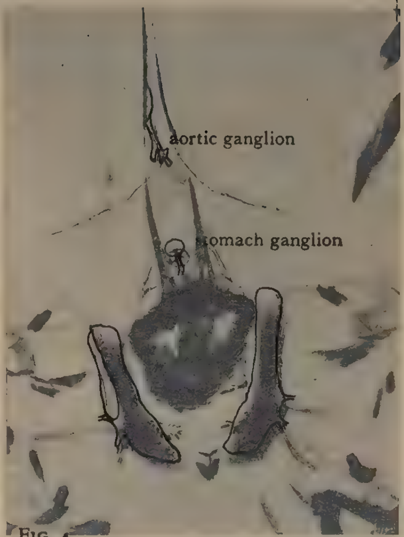
aortic ganglion
stomach ganglion

FIG. 4.

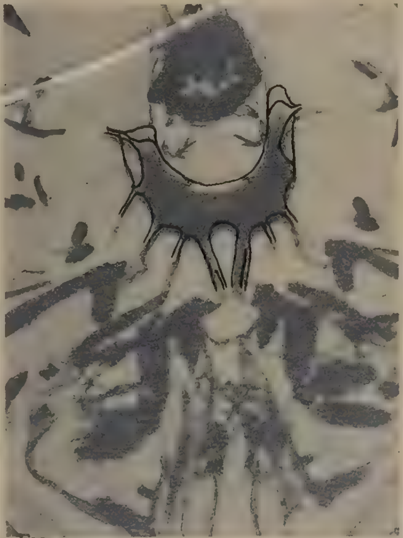

FIG. 5.

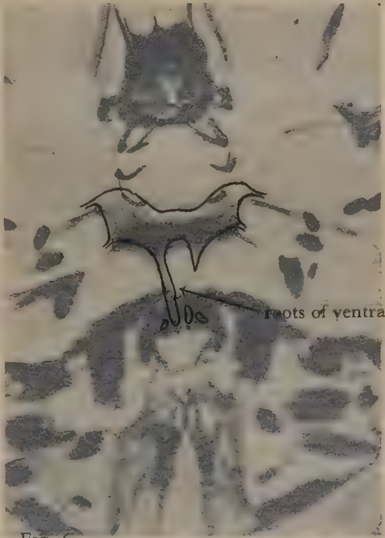
roots of ventral chain

FIG. 6.

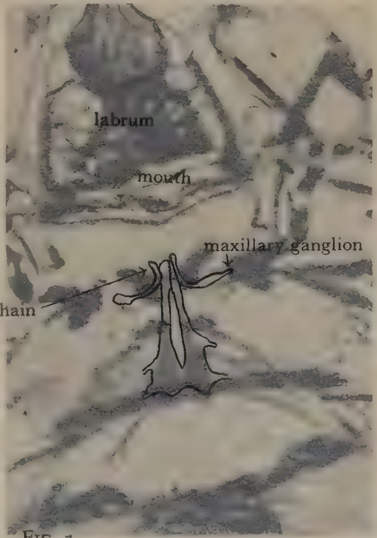
labrum
mouth
maxillary ganglion

FIG. 7.

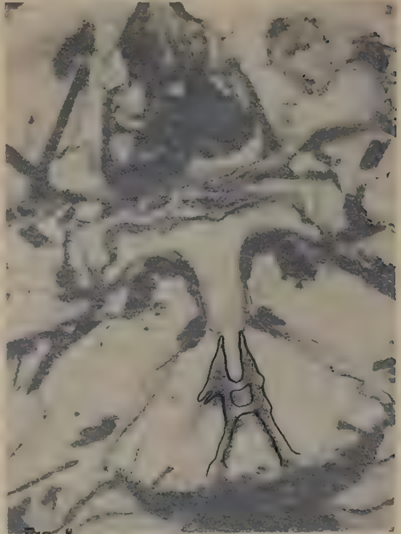

FIG. 8.

GIGANTOCYPRIS

Photomicrographs of successive thick sections on which the reconstruction of the nervous system, Fig. 13, was based. Nos. 1–6 are from series C, and 7–8 from series D. 110µ thick sections stained Malloy Triple Stain. The use of a lens is recommended for the examination of details in the plate.

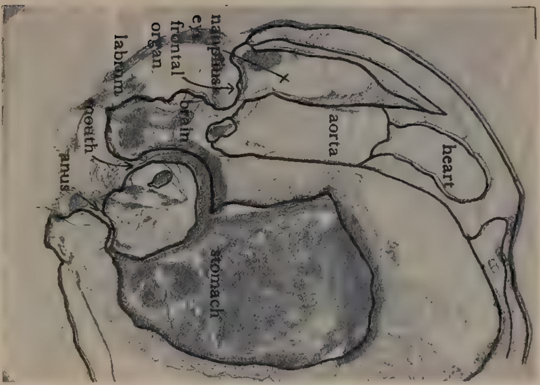
nauplius eye
frontal organ
labrum
mouth
anus
brain
aorta
heart
stomach

FIG. 1. Photomicrograph of sagittal section to show heart, aorta, nerve ring, gut, etc.

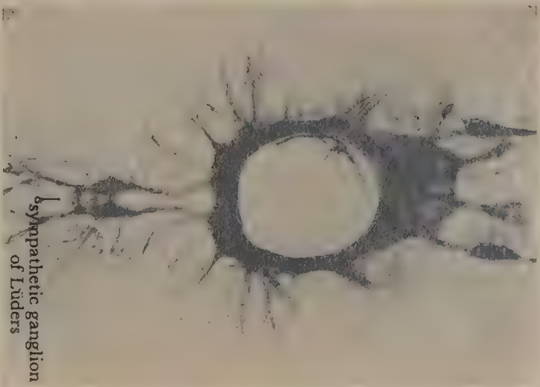
sympathetic ganglion of Lüders

FIG. 2. Photomicrograph of complete nerve ring and chain system dissected out.

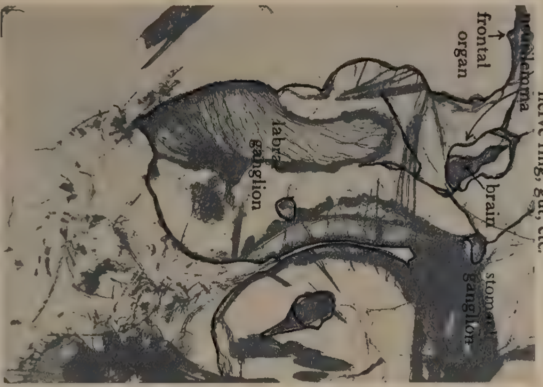
frontal organ
neurilemma
brain
stomodaeal ganglion
labral ganglion

FIG. 3. Photomicrograph of sagittal section to show visceral nervous system.

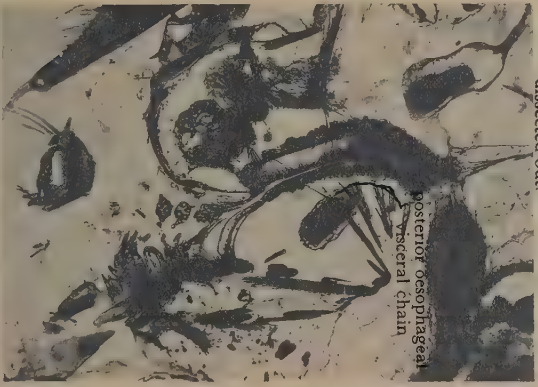
posterior oesophageal visceral chain

FIG. 4. Photomicrograph of parasagittal section to show fine visceral chain posterior to oesophagus.

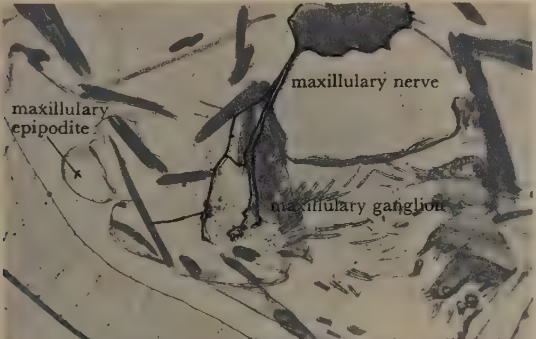
maxillulary nerve
maxillulary epipodite
maxillulary ganglion

FIG. 5. Photomicrograph of section through maxillule including complete maxillulary nerve and basal maxillulary ganglion.

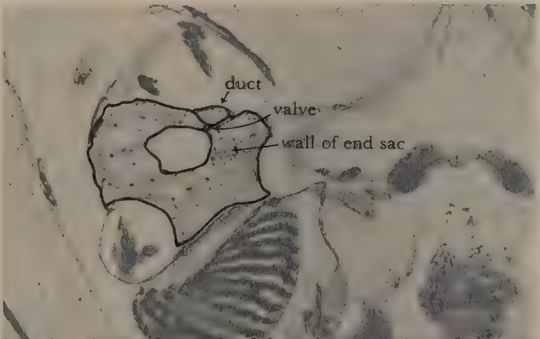
duct
valve
wall of end sac

FIG. 6. Photomicrograph of frontal section through base of antenna to show antennal gland.

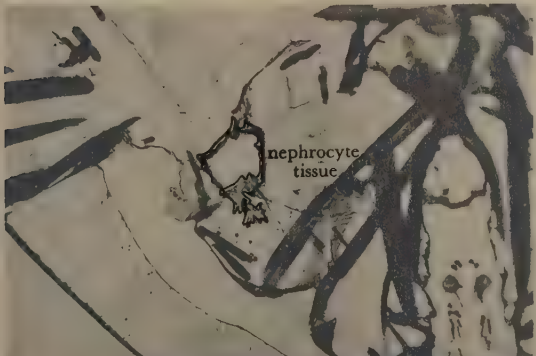
nephrocyte tissue

FIG. 7. Photomicrograph of section through nephrocyte tissue in maxillule.

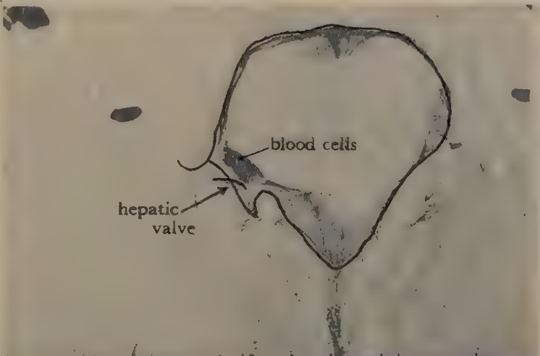
blood cells
hepatic valve

FIG. 8. Photomicrograph of section through heart to show hepatic valve.

GIGANTOCYPRIS

All sections stained with Chlorazol Black. Nerve ring stained Borax Carmine.
The use of a lens is recommended for the examination of details in the plate

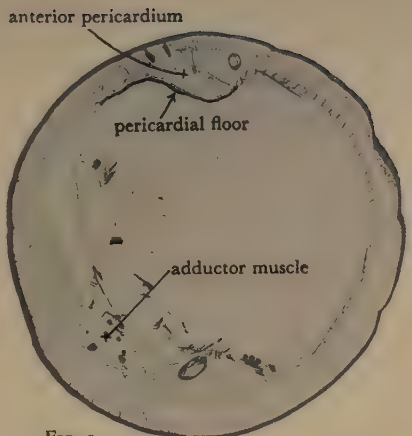
anterior pericardium
pericardial floor
adductor muscle

FIG. 1.

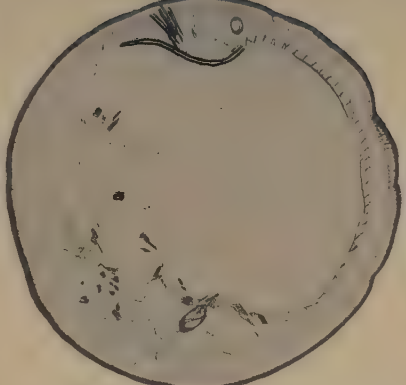

FIG. 2.

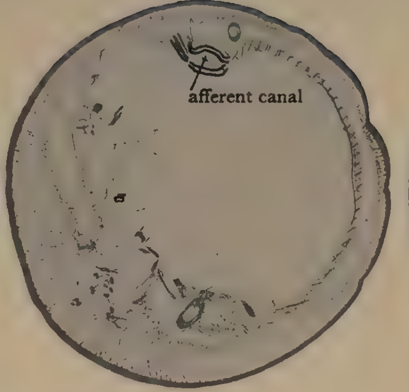
afferent canal

FIG. 3.

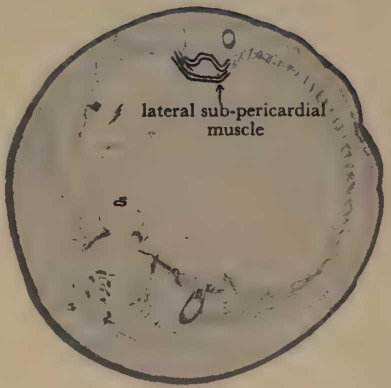
lateral sub-pericardial muscle

FIG. 4.

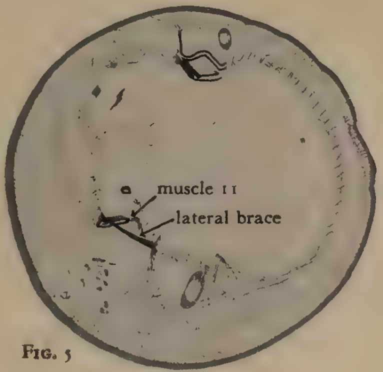
muscle 11
lateral brace

FIG. 5

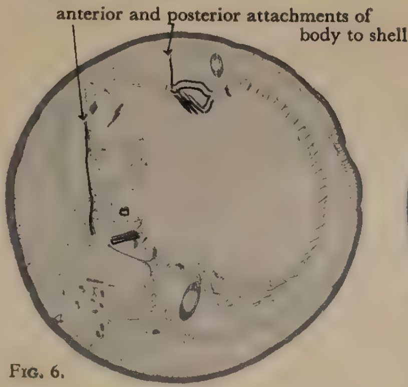
anterior and posterior attachments of body to shell

FIG. 6.

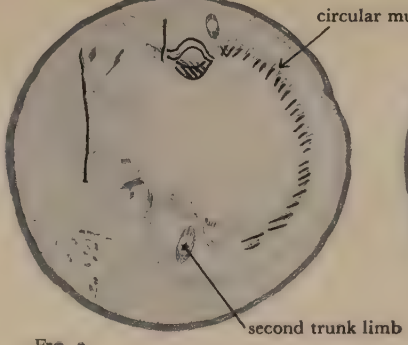
circular muscles
second trunk limb

FIG. 7.

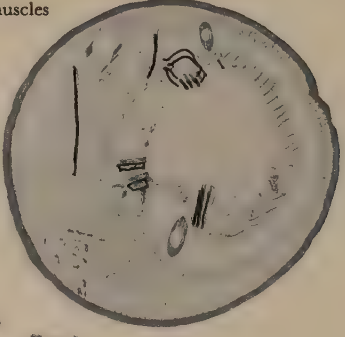

FIG. 8.

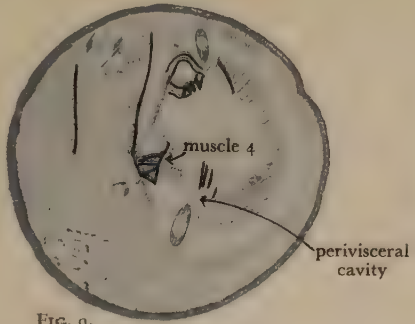
muscle 4
perivisceral cavity

FIG. 9.

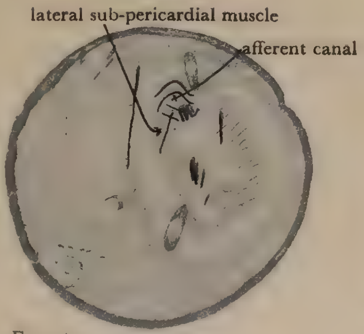
lateral sub-pericardial muscle
afferent canal

FIG. 10.

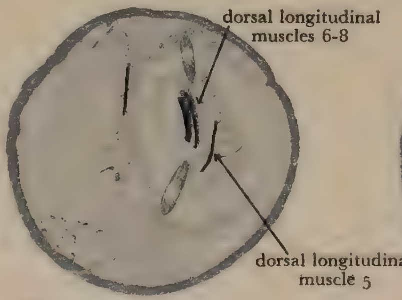
dorsal longitudinal muscles 6-8
dorsal longitudinal muscle 5

FIG. 11.

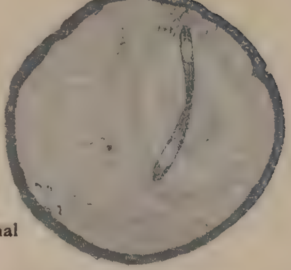

FIG. 12.

GIGANTOCYPRIS

A series of 12 successive thick sections showing details of posterior pericardial floor and associated musculature from which figures 7 a and b were reconstructed. Chlorazol Black.
The use of a lens is recommended for the examination of details in the plate.

[*Discovery Reports. Vol. XIX, pp.* 245–284, *Plates XLIII–LXVIII, July* 1940]

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INVESTIGATIONS

WHALE MARKING

PROGRESS AND RESULTS TO DECEMBER 1939

By

GEORGE W. RAYNER

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WHALE MARKING

By George W. Rayner

(Plates XLIII–LXVIII; Text-fig. 1)

INTRODUCTION

In the Discovery Committee's investigations on the habits and life histories of whales, observations on the living animal have formed an essential part of the programme, and for the purpose of tracing movements and migrations a method of marking has been devised. The marks, which are fired from a shot-gun, are in the form of small darts each bearing a serial number. They become embedded in the whale's blubber and are found when the whale's carcase is dismembered by the whalers. The geographical position at which each mark is fired is recorded and a reward offered for its return with appropriate data.

The pursuit of whales is not easy, for they tend to follow an erratic course and they offer only a fleeting target when they break surface to breathe. Consequently a small, handy vessel, able to alter course quickly, is necessary for the work, and the R.R.S. 'William Scoresby' was built largely for this purpose. She is an oil-burning steam-driven ship of 715 tons displacement, constructed on the lines of a modern whale-catcher, but designed also for trawling and general oceanographical research (see *Discovery Reports*, vol. 1, pp. 147, 148–9, 174–80). During the whole of the four whaling seasons of 1934–35 to 1937–38 this ship has been engaged solely in marking the commercially important species of whales on the pelagic whaling grounds of the Antarctic, which have thus been covered from 110° E westwards almost to Peter I Island in the Pacific sector of the Southern Ocean.

In addition, intensive whale-marking on the whaling grounds around South Georgia has been carried out with hired whale-catchers during the three seasons 1934–35 to 1936–37. These expeditions, in the 'William Scoresby' and in the hired whale-catchers, have resulted in more than 5000 whales being marked, their distribution covering almost the whole area of the Antarctic seas in which modern whaling has been undertaken. Marks have been returned from whalers operating in all the parts of the Antarctic grounds visited by them since the marking was accomplished, and some marks have also been recovered in tropical and subtropical waters where whaling takes place during the southern winter. Only a comparatively small number of marks has been returned as yet, namely, 203 marks from 187 whales, but as a mark can be expected to remain in the whale for many years returns should continue over a long period. In the meantime, more especially because of the war, it has been thought expedient to publish the results so far obtained, and a full list of the marks returned, with data, is given at the end of this paper, Tables VI, VII and VIII.

Although the Discovery Committee is not at present planning further whale-marking expeditions an attempt has been made to enlist the co-operation of commercial interests in this work. In 1938–39 successful collaboration with the Reichstelle für Walforschung in Hamburg resulted in some whale-marking by the German whaling expeditions and about 200 whales were marked during that season.

I wish to take this opportunity of expressing my thanks to the many people who have contributed towards the success of this work in the field; first to my colleagues, Mr E. R. G. Gunther, Dr T. J. Hart, Mr H. P. F. Herdman and Mr A. H. Laurie, all of whom have been in charge of expeditions in whale-catchers from South Georgia or in the 'William Scoresby'. I wish, further, to express my deepest gratitude to Capt. Johan Endresen and his brother, Endre Endresen, gunners in the 'William Scoresby', who so skilfully developed the powers of that ship for whale-marking, and to Capt. Hans Olsen, gunner and captain of whale-catchers used around South Georgia during four seasons. Finally, I thank all those members of the whaling community with whom we came in contact on the whaling grounds, especially Capt. Abrahamsen, manager of the Compaña Argentina de Pesca's whaling station at Grytviken, who so facilitated the work on the South Georgia grounds, and the many captains, managers and gunners of the pelagic whaling fleet who gave such ready assistance, in so many ways, to the 'William Scoresby'.

EVOLUTION OF THE MARK

There are many obvious difficulties in designing a mark suitable for such an animal as a whale. It should be such that it will be carried permanently by the whale in a position from which it cannot be dislodged by healing processes, yet it must not inflict injury or itself suffer corrosion. It must be simple in form, so that it can be produced in large quantities at a reasonable cost and, moreover, it must be of such distinctive appearance that the whaler, in the stress of his long working day, may readily recognize it in the welter of blood, meat, bones and rapidly moving machinery among which he toils. At an early stage in the Discovery Committee's activities experiments were made with a mark resembling an enlarged drawing-pin constructed of silver-plated annealed iron or, eventually, "Staybrite" steel. The point, about 2½ in. long, carried three barbs, and sprang from a disc 1¾ in. in diameter; it was inscribed on the leading face with the legend, "Reward paid for return to Discovery Committee, Colonial Office, London", and a serial number. This mark was attached to a long wooden shaft, which fitted, by means of felt wads, a 12-bore gun. When fired into the whale, the point penetrated the blubber, the disc remained visible on the exterior, whilst the wooden shaft became disengaged and dropped off (see *Discovery Reports*, vol. 1, pp. 208–10).

Many whales were marked with this form of mark, but not one has ever been recovered. Blubber is known to suppurate readily and it was found at the biological station at South Georgia that a healthy whale is able to rid itself of deep-rooted parasites such as *Penella* (Mackintosh and Wheeler, 1929); there is no doubt that the mark, penetrating the blubber no more than 2½ in., was quickly rejected. When it was realized that this mark must be looked upon as a failure several other patterns were considered, but they all lacked simplicity of structure, making their cost of production prohibitive. Finally, in 1932, a most suitable form was designed consisting only of a metal tube with a leaden head, of sufficient diameter to fit a 12-bore gun, giving the necessary ballistic balance. The tube, 10 in. long, was made of aluminium and fitted into the cartridge carrying the charge, so enabling loading to be accomplished with facility and speed. Along the tube were engraved the words, "Reward for return to Colonial Office, London", and a serial number. This mark was designed to bury itself completely in the blubber and to be found when the whale was flensed upon the factory "plan".

In an experimental trial with these marks around South Georgia during the season 1932–33 more than 200 whales were marked in three weeks. From these whales several marks were recovered during that season, and still further ones were found and returned the next season. These later recoveries showed that whilst the aluminium used in the construction of the tubes suffered some corrosion during the time it was carried by the whale, the method and design of the mark were satisfactory. To overcome the difficulty of corrosion stainless steel ("Staybrite") was substituted for the aluminium. An extensive marking programme was then planned and executed using this form of mark, which has continued to be very satisfactory. It is easy to handle quickly when shooting and considerable accuracy can be attained up to a range of 70–80 yds. or even more. Normally the marks are retained and, although no doubt some escape detection when the whale is processed, they are readily found by the whalers. With the use of stainless steel no corrosion whatever takes place, even after some years, and the engraved number on the mark is thus always legible.

The guns used are single-barrelled 12-bore weapons of a modified Webley design. They are of straightforward construction, but strengthened in the breech and barrel to carry the heavy projectile.

PRACTICAL METHODS AT SEA

As already stated, the 'William Scoresby' was built on the lines of a modern whale-catcher for the primary purpose of serving as a whale-marking vessel. A description of the ship and her gear has been given in detail by Kemp and Hardy (1929), but one or two further remarks may be added. As explained by these authors a fo'c'sle head was added to the vessel's bows in 1927, and this has proved to be of the very greatest service during her whale-marking cruises. Indeed, it is very doubtful if more than an insignificant number of whales could have been marked without this superstructure. The marking was done entirely from the platform offered by the deck of the fo'c'sle head, a position roomy and well placed, giving a good angle of fire down on to the whale. At the outset of the marking programme a light gangway was constructed running fore and aft from the main bridge to the fo'c'sle head. This offered easy and rapid access from the bridge to the shooting position, avoiding the necessity of descending to the main deck, which was often awash, and climbing again to the fo'c'sle head. A canvas dodger was fitted to the rails of the fo'c'sle head and reduced considerably the exposure experienced during the long periods spent in this position whilst in pursuit of whales. It was necessary to furl the dodger during rougher weather, when seas broke over the bows, at those times when additional protection would have been greatly appreciated; but for the most part marking was impracticable under the conditions in which this shelter was removed.

Besides the ship's normal complement of twenty officers and men, all of whom were, of course, British, the 'William Scoresby' carried one scientific officer in charge, and during the first two whale-marking commissions a professional Norwegian whale gunner who took charge of the ship when the chasing and marking of whales was in progress. In the later commissions this work devolved upon the scientific and executive officers.

For whale-marking around South Georgia a modern whale-catcher was hired complete with a Norwegian gunner and crew from one of the companies operating around the island. On board the whale-catcher the marking was done from the gun platform. In order to give some protection to the markers in this exposed situation empty 90-gallon drums were securely lashed in the angles of the gun platform. Small canvas dodgers were fitted to these drums and the marker ensconced himself therein, thus avoiding some of the wind and spray to which he would otherwise have been exposed. A member of the Committee's scientific staff was in charge of these cruises.

Upon the scientific officer, besides the general planning of the work in the field, fell the duty of making all notes and observations during the course of marking. This essentially consisted of the recording of the serial number and result of each mark fired, the species of whale marked and the date and position of marking. The result of each shot fired can be decided with considerable confidence, for after a very little experience the flight of the mark can be followed with the eye. At first the result of each shot was recorded according to an elaborate scheme containing many possibilities, for we were not then familiar with the behaviour of the mark. Eventually it was found possible to reduce this elaborate scheme so that a mark fired was considered to result in a hit, a possible hit, a miss or a ricochet. On very rare occasions a mark so far escaped observation that it was impossible to decide what had become of it; in these circumstances the result was recorded as "no verdict".

No fewer than five of the Discovery scientific staff have served in charge of whale-marking cruises and minor individual variation in the recording of observations is naturally to be expected.

SCOPE OF THE MARKING ACCOMPLISHED

The complete programme of marking carried out by the Discovery Committee with this tube pattern of mark covers no less than eight separate expeditions. The first one, 1932–33, was of an experimental nature and was carried out from South Georgia, a hired commercial whale-catcher being employed. The experiment lasted from 20 December 1932 to 12 January 1933, and the whales considered to be effectively marked were 202 Fin, two Blue, two Humpback and one Sei. Although operations extended beyond the range of the South Georgia whalers, all the marking was carried out in the neighbourhood of the island, the farthest point visited being the Shag Rocks. When the results of this experiment promised success the 'William Scoresby' was commissioned and then spent four whaling seasons on the pelagic grounds along the Antarctic ice-edge. This was only made possible by the very willing co-operation of the whaling companies working in the areas visited, for although the 'William Scoresby' has a large bunker capacity and a greater range of operation than a commercial whale-catcher, it was necessary to refuel at intervals. Fuel oil was provided by the factory ships on the grounds and so enabled the marking vessel to continue her work with only the occasional interruption of a few hours throughout a season of four months' duration. Each of these four commissions of the 'William Scoresby' lasted about seven months, and this allowed a period of four months, roughly coincident with the legal southern whaling season, to be spent actually on the grounds. During the first three of these commissions, 1934–35 to 1936–37, the ship sailed from London about the middle of October and proceeded to Cape Town; after final preparations there she departed for the whaling grounds towards the end of November. Since she was dependent on fuel-oil supplies from the factory ships, their departure northwards at the end of the season's operations put a period to the 'William Scoresby's' activities, but by taking a last supply of fuel oil as late as could be arranged it was possible to remain in the south some ten to fourteen days longer than the whalers. The ship then returned to the Cape and so back to London.

During each of these three seasons an area extending from the meridian of Greenwich to 105° E longitude was covered by a series of courses running parallel or roughly diagonally to the edge of the pack-ice. Endeavours were made to avoid the areas covered by the catchers of any factory ship and for the most part the 'William Scoresby' worked to the north of the whalers and away from the pack-ice, although visits thereto were made in search of Blue whales and for shelter during some of the spells of violent weather that were frequently experienced. The results of these cruises are set out in Table I, and it will be seen that the first two seasons gave very similar figures, a total of almost 700 whales being marked on each occasion; the third season's work was more successful and a total of 960 was reached.

The species of whale chiefly marked was the Fin, the most abundant whale on the Antarctic whaling grounds and for the pursuit of which the 'William Scoresby' is most suited. Humpbacks and Blues were also marked in moderate numbers, although the last species was much more difficult to pursue successfully than the other two. The very successful third season, 1936–37, gave a large addition to the number of Blue whales marked.

While the 'William Scoresby' was engaged on this main area of the pelagic whaling grounds a hired whale-catcher operated from South Georgia during each of these three seasons. The period of each cruise was roughly two months and lay between the extreme dates of 20 November and 9 February, that is, it comprised the early and middle parts of the season. During the first season, when mostly Fin whales were marked, work was restricted to the vicinity of the island and of the Shag Rocks, which lie about 140 miles westward of the northern part of South Georgia. The next season, 1935–36, brought ice close to the island and it was, as periodically happens at South Georgia, predominantly a "Blue whale season". Marking this season extended to a greater distance and mostly lay between east and south of the island. The season's work was very successful, for in addition to a good total of Blue whales many Fins were marked. Following this, the season 1936–37 was remarkable for an almost complete absence of Blue whales from South Georgian waters and was, overwhelmingly, a "Fin whale season". Operations were very largely carried on around the Shag Rocks and only one Blue whale was marked as opposed to 718 Fins.

TABLE I

Whales estimated to be effectively marked

Expedition	Whales effectively marked						
	Blue	Fin	Sei	Humpback	Right	Sperm	Total
R.R.S. 'William Scoresby'							
1934–35	87	515	10	68	—	7	687
1935–36	90	371	1	200	—	15	677
1936–37	194	532	3	216	—	14	959
1937–38	23	683	8	56	—	16	786
South Georgia							
1932–33	2	202	1	2	—	—	207
1934–35	69	299	—	1	8	—	377
1935–36	202	584	—	4	—	—	790
1936–37	1	719	4	—	—	—	724
R.R.S. 'Discovery II'							
1933–35	—	2	—	—	—	—	2
1935–37	—	—	—	—	—	—	—
1937–39	—	8	1	1	—	—	10
Totals	668	3915	28	548	8	52	5219

During the season 1937–38 no whale-catcher was hired for marking, but the 'William Scoresby' recommissioned a fourth time for this work. The programme of work for this commission was planned to be complementary to the whale-marking already done, which, as will be explained later, had shown that whales did not spend much time in the neighbourhood of South Georgia, but only passed through it on passage to more southerly feeding grounds. During the 1937–38 season whales were to be marked north of South Georgia before or at the commencement of the whaling season and, later, farther south between South Georgia and the pack-ice of the Weddell or Scotia Seas. In addition, whales were to be marked between the longitudes of the South Sandwich

Group and Bouvet Island, a region then unvisited. Marking was also to be done around the South Shetland Group, where whales had not been molested for some seasons, and was to be extended into the Bellingshausen Sea as far westwards as Peter I Island, a region neglected by factory ships and untouched by whaling except for operations, based on the harbours on the eastern side of the sea, in the earlier days of the industry. This was an ambitious programme for one season's work, but it was almost wholly accomplished. Bad weather and inability to find whales north of South Georgia at the outset and again later in the season in the regions towards Peter I Island caused the only failures to complete the plan. This season, as far as marking was concerned, was also a "Fin season" and very few of the other species were marked.

The whales estimated as effectively marked on each of these expeditions are shown in Table I, arranged according to species. They total 668 Blue, 3905 Fin, 547 Humpback, 27 Sei, 8 Right and 52 Sperm whales.

It is useful here to explain how the numbers of whales "effectively" marked, as given in this table, are calculated. These totals have been reached after a study of the log books of each whale-marking cruise and after the following adjustments have been made. Firstly, from the total of hits recorded there have been deducted all duplicate hits. Secondly, all those marks noted as protruding are also deducted, except when such a protruding mark has already been returned, for it is considered that these protruding marks must usually soon be lost by the whale. To the number thus obtained there has then been added the few marks recorded as misses or possible hits which have so far been returned, and, finally, half the remaining "possible hits" have been considered to be valid hits and added to the total. This final total is the one given in the table for the numbers of whales considered to be effectively marked on each cruise, and is thought to be as near as can be approached to the true figure. At the same time, with one exception, these totals probably represent the maximum number of whales marked, for it is not always possible to tell if a whale is marked more than once. Also, many more marks will be protruding, perhaps only a very little, than those observed and noted, and the eventual loss of these will further depress the true total.

The one exception mentioned is the total for the whales marked around South Georgia in the season 1934–35: it is given as 377, but this is almost certainly too low. On this cruise a deliberate attempt was made to mark every whale twice. There is no doubt that this was very far from being accomplished, but, after the adjustments described above had been made and after single marks returned from whales had been allowed for, the number of hits recorded was halved to give the total in the table. Apart from this one season the figures given in Table I for each season's results are looked upon as reasonably comparable.

The R.R.S. 'Discovery II' has carried marks and guns and, when occasion offered, has marked whales. She is, however, not the type of ship able to pursue whales, and any attempt to do so would interfere with her ordinary work. An occasional shot when whales approach the ship is the most that can be done.

A schematic representation of the distribution of the whales marked is given on

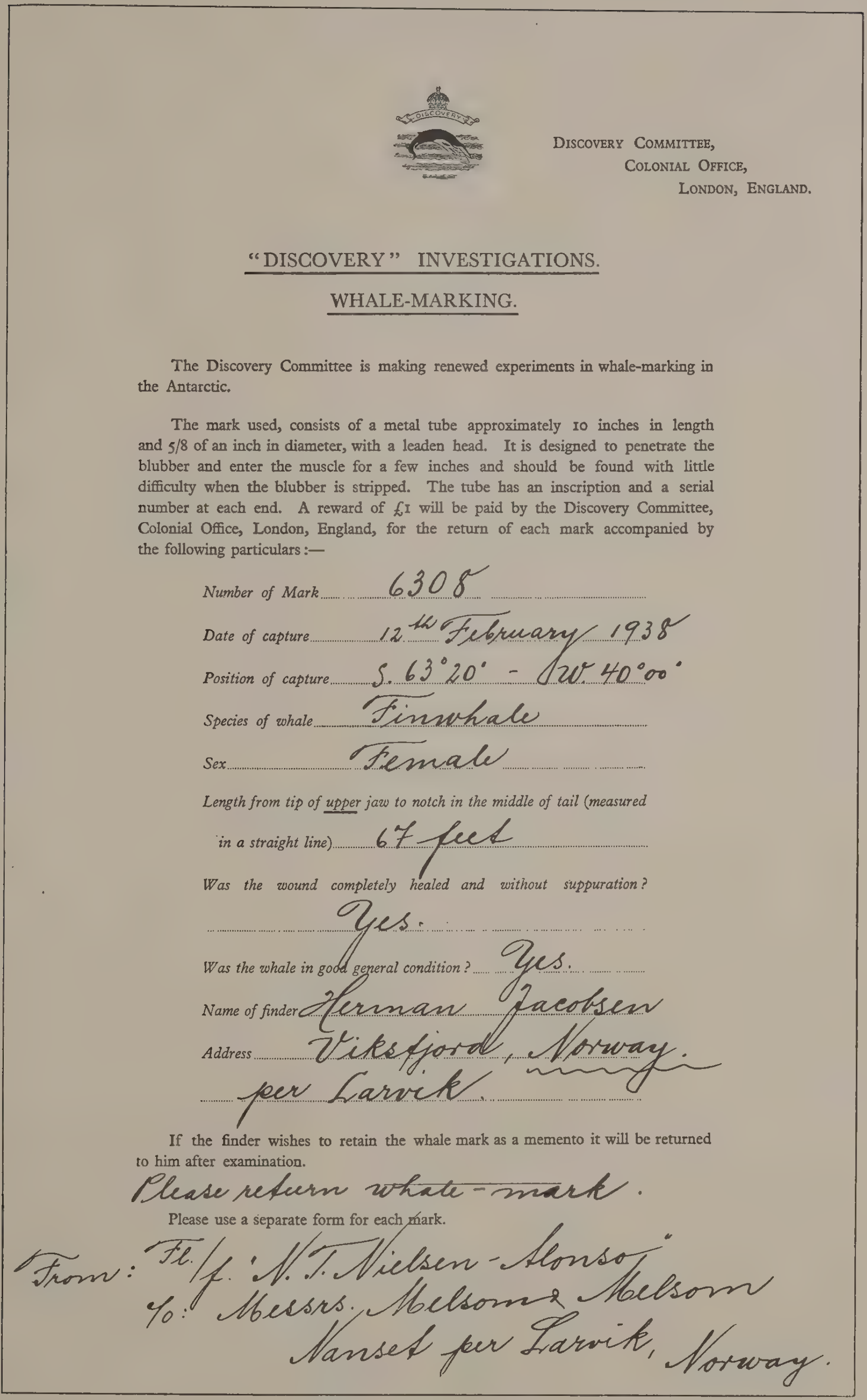
Plate XLV. The diagonally hatched areas show where marking has been chiefly conducted and where most whales have been marked. There is a comparatively small area of intensive marking around South Georgia and, around the Shag Rocks, a smaller area, of seventy miles radius, indicated by denser cross-hatched shading, where more than 600 have been marked. There are two other extensive areas in which relatively large numbers of whales have been marked, one off Queen Mary Land (85–95° E) and a second, much larger, extending westwards from Enderby Land (15–50° E). In addition, whales in smaller numbers have been marked over an immense area connecting and extending these principal regions; on the chart the continuous longitudinal lines show where this marking has been relatively dense, the broken lines where it has been sporadic.

Blue whales have been marked around South Georgia chiefly between east and south of the island. On the pelagic grounds the majority have been marked in the most easterly part of the area and off Enderby Land. Very few Blue whales have been marked to the west of the Greenwich meridian except those around South Georgia. Fins have been marked over the whole area, but least in the extreme east. The large numbers of whales marked around the Shag Rocks are exclusively Fins, and many more have been marked in the South Georgia region. Humpbacks show the most localized distribution. The greatest number of this species has been marked off Queen Mary Land, where they constitute a large proportion of the total. Some have been marked in the diagonally hatched area lying athwart the 30° E meridian, but there they are more scattered than in the east. The only other region where they have been met in any abundance is off Adelaide Island in the Bellingshausen Sea, where a number have been marked in a comparatively small area.

RETURN OF MARKS

Marks have been found in various ways. Complete penetration does not always occur, and in these instances the mark remains protruding from the animal and so is readily seen. Such marks have been observed in whales before even the whale gunner has fired his harpoon, and they have been easily collected after the whale has been secured. As explained earlier, any mark noted as protruding and not returned has been considered to be lost from the whale and so is not included in the totals of marked whales given in Table I. The majority of the marks returned are, however, found when the whale is being handled on the "plan" by the flensers and lemmers. Should they escape detection at this stage of the treatment of the whale carcase they usually come to light in the various apparatuses employed in working up the blubber and meat.

In addition to the return of the actual mark as found, data concerning the marked whale are asked for. Forms are supplied to the whaling companies to be filled in with the details of each whale found to be bearing a mark. A facsimile of one of these forms completed with the required data is given, Fig. 1. In the majority of cases it is possible to supply all the information required, but when a mark is not found until it reaches the boilers only the date and approximate position of capture may be available. These, however, are the essential facts, and the species can be ascertained from the notes



DISCOVERY COMMITTEE,
COLONIAL OFFICE,
LONDON, ENGLAND.

"DISCOVERY" INVESTIGATIONS.

WHALE-MARKING.

The Discovery Committee is making renewed experiments in whale-marking in the Antarctic.

The mark used, consists of a metal tube approximately 10 inches in length and 5/8 of an inch in diameter, with a leaden head. It is designed to penetrate the blubber and enter the muscle for a few inches and should be found with little difficulty when the blubber is stripped. The tube has an inscription and a serial number at each end. A reward of £1 will be paid by the Discovery Committee, Colonial Office, London, England, for the return of each mark accompanied by the following particulars:—

Number of Mark 6308

Date of capture 12th February 1938

Position of capture S. 63°20' - W. 40°00'

Species of whale Finwhale

Sex Female

Length from tip of ***upper*** *jaw to notch in the middle of tail (measured in a straight line)* 67 feet

Was the wound completely healed and without suppuration? Yes.

Was the whale in good general condition? Yes.

Name of finder Herman Jacobsen

Address Viksfjord, Norway.
per Larvik.

If the finder wishes to retain the whale mark as a memento it will be returned to him after examination.

Please return whale-mark.

Please use a separate form for each mark.

From: Fl./f. 'N.T. Nielsen-Alonso'
c/o: Messrs. Melsom & Melsom
Nanset per Larvik, Norway.

Fig. 1. Facsimile of completed whale-mark form. (About 2/3 actual size.)

made at the time of marking. Even though the mark is found in the boilers, under modern organization and speed of treatment of whale carcases, the position of capture can usually be given within a radius of twenty miles or so, which can be accepted as near enough for our purposes.

The interest and attention given to these demands by all concerned, from the labourers on the plan to the managers and directorates of the whaling companies, may once more be mentioned, for the success of the work is wholly due to their cooperation and to the care taken in rendering full and accurate returns. At an early stage of the experiments it was found that some of the whalers wished to retain the mark as a memento, and as stated on the form it is now sent to the finder after examination if he so desires.

MOVEMENTS OF WHALES

In plotting the movements of whales as indicated by the returned whale-marks, the data available for each species have been arranged according to the length of time that has elapsed between marking and capture. The marked whales taken during the same season as that in which they were marked are referred to as the 0-Group, those taken the following season after an average lapse of one year as the 1-Group, those after two years as the 2-Group, and so on. Marked whales have also been captured in warmer waters, in the region of the tropics, during the southern winter in the intervals between the Antarctic whaling seasons. These are almost entirely Humpbacks, and they have similarly been arranged in groups denoted as ½-Group, 1½-Group, and so on. The ½-Group includes those marked in the southern summer and killed in the following winter, the 1½-Group those killed in the next winter but one, and so on, the average period between marking and capture being 6 months, 18 months, 30 months and so on.

The positions of marking and capture are plotted on charts (Plates XLVI–LXVIII); they are connected by straight lines as a matter of convenience. The lines, naturally, are not intended to indicate the course taken by the whale after marking; they do, however, represent a resultant of these movements and are conveniently referred to as tracks. The tracks of all the whales of each species taken during the same season as they were marked (0-Group) are shown together on the same chart (Plates XLVI, XLVII, LIII, LIV, LXII), although marks returned during five different seasons, 1932–33, 1934–38, contribute. Similarly, all the tracks given by the marks returned the first season after marking are shown together (Plates XLVIII, XLIX, LV, LVI, LXIV), and so on. In this way each chart gives a composite picture of the movements of whales after a definite interval of time, but is derived from marking which extended ultimately over five seasons.

It will be convenient to consider the movements of the three species separately.

MOVEMENTS OF BLUE WHALES

The total number of Blue whales estimated to be effectively marked is 668 and marks have been returned from thirty-three of these whales. The majority of the returned marks, namely eighteen, have been recovered the same season as they were fired. These constitute the 0-Group, and they have been returned after an average period of twenty-one days and after times varying from a few hours, the whale having been taken the same day as marked, to eighty-eight days. Around South Georgia marked Blue whales in this 0-Group (Plate XLVI) have not been taken after a longer interval than six days, but Blue whales marked in the vicinity of South Georgia have been recovered a considerable time later far to the southward on the edge of the pack-ice. Thus, one whale (No. 3853) was taken after eighty-eight days and had travelled more than 500 miles south-westerly, a second (No. 4563) after thirty-two days and at a distance of more than 300 miles to the south-east. From this it appears conclusively that Blue whales found in the region of South Georgia during that part of the season when marking took place are on the move and presumably migrating, only passing the island on their way southwards. The short movements of those whales marked and captured on the South Georgia grounds show, in general, a southerly trend. Farther south, a mark, No. 10638, was fired into a whale in a position almost on the indicated track of No. 4563 and near the edge of the pack-ice, though in a subsequent season (Plate XLVII). In nine days this whale had travelled 360 miles in an east-south-easterly direction. From these movements it seems evident that, in general, Blue whales found around South Georgia move during the whaling season in a southerly direction, and probably keep on moving in this way until the edge of the pack-ice is reached, where they may turn either to the east or to the west.

Only on the pelagic grounds to the east, between 15 and 50° E, have enough recoveries been made to show any definite trends of movement (Plate XLVII). In this region the time between marking and capture varies from two to fifty-nine days and, as most of these whales have been marked in a rather restricted portion of the area, their progressive movement can be followed. Without exception the movement lies between west and south-west and, further, all these whales, with but one exception, were marked in the same season, 1934–35, and during January, to be recovered at various times up to the end of March.

A consideration of the movements of the factory ships during this season (1934–35), as shown on the charts given by Hjort, Lie and Ruud (1935), is of considerable interest. These show that after the initial search period during December, when ships were well spread out over a large area, there occurred in the latter part of January a marked movement of factory ships towards Enderby Land, and a concentration was formed there. During February this concentration moved westwards and was joined by other factory ships from the north, so that an area of the whaling grounds to the west of Enderby Land, between 30 and 40° E, was subjected to a very intensive slaughter. This area was still occupied during March, although at the beginning of that month a number of factories broke back eastwards towards Enderby Land, only to return westwards later. Large catches of Blue whales were made in this region during January (2229) and February (2052). There can be no doubt that there was a very large number of Blue whales off Enderby Land and a little to the west during January of this season, and marking shows that this body of whales moved westwards during the course of the following two months. Further, all evidence goes to show that there was no easterly movement of any importance during this time. The experience of the 'William Scoresby' this season was that whales of any kind were almost absent between 60 and 80° E during the two periods spent in crossing that region. The whalers themselves believe that this is a blank area; an opinion expressed by Hjort, Lie and Ruud (1934), who say that there are not enough whales to make whaling profitable south of Kerguelen from the end of January onwards. Although several factory ships passed through this region in January 1935, none stopped long, and for the rest of the season the waters to the east of Enderby Land were deserted.

It seems, therefore, that during this season, 1934–35, from January onwards, Blue whales from waters off Enderby Land moved steadily westwards, reaching as far as 15° E by the end of March. This movement was followed and exploited by a number of factory ships.

The very high percentage, 8·05 per cent, of recoveries of marks from Blue whales marked by the 'William Scoresby' during 1934–35 is due to the marking of whales in this stream of movement. Between 50 and 40° E twenty-nine Blue whales were marked from 21 January to 1 February. This number must be understood to include all those whales carrying marks logged as protruding and considered to be effective only during the season of marking, and is actually six more than it would be if estimated in the manner explained above (p. 254) for arriving at the number of effectively marked whales in Table II. Three whales carrying protruding marks were killed during that season and so are included in both totals. Of the twenty-nine marked whales, two were females accompanied by calves and two others were calves. These four whales would be neglected by the whalers and so, as far as figures for this season are concerned, may be disregarded. There were thus twenty-five marked Blue whales available for capture in the area mentioned: seven of these were killed before the end of the season. This is 28 per cent and, it must be realized, is a minimum figure, for some marks may have escaped detection after the capture of the whale.

TABLE II

Marked Blue whales killed in each group

Season of marking	Estimated number marked	Returned						
		Same season 0-Group	1st season 1-Group	2nd season 2-Group	3rd season 3-Group	4th season 4-Group	5th season 5-Group	6th season 6-Group
1932–33	2	—	—	—	—	—	—	—
1934–35	156	11	3	2	1	2		
1935–36	292	6	3	2	—			
1936–37	195	1	—	—				
1937–38	23	1	1					
Totals	668	19	7	4	1	2	—	—

Subsequently Blue whales were marked farther west, but none of these were reported as killed that season; it may be that this marking was done outside the main stream of whales, possibly on its northern fringe.

That this body of Blue whales was subjected to considerable persecution is also shown by the capture of a marked female Blue whale only 69 ft. long (No. 2910); when marked it had been estimated to be 60–65 ft. in length. At this length, 10 ft. below the average of the season for the whole Antarctic, the whale appeared, when free at sea, to be comparatively diminutive.

The experience of the manager of a factory ship a year earlier, recorded by the late Sigurd Risting (1935), suggests that a movement similar to this had taken place that season, 1933–34. In January this manager had searched southwards in a catcher and had met the ice-edge near Prinsesse Ragnhild Land, almost 250 miles from his ship, but had seen no whales. In February, however, many Blue whales were to be found here where there had been none the previous month. The region must have been situated between 10 and 30° E and the arrival of Blue whales in February corresponds with the movements of marked whales the next year; it is very probable that some of them had come here from waters to the east, off Enderby Land.

One other mark (No. 7705), from a later season (1936–37), has been recovered in this area. It was fired early in the season, in December, and recovered in February, and indicates a general south-westerly trend of movement. One is inclined to think that after being marked the whale may have proceeded eastwards, later turning to make the westerly movement so marked in the earlier season. On the other hand, the movements of the factory ships during this season (1936–37) show a contrast to their usual movements as outlined above, to which they had held for several seasons. No concentration was formed off Enderby Land and consequently no movement from there to the westward was made. The weekly positions of factory ships as shown by Hjort, Lie and Ruud (1938) are much more widespread, and their movements greater and more erratic. The movement in the longitudes in which the whale was marked and killed is, in general, southerly. Whilst the movements of the factory ships are different from those of previous seasons, there is also a very marked decrease in the catch of Blue whales in this area during February as compared with those of former seasons. This may be due to over fishing in this region and the breaking up of regular whale movement by excessive harrying and slaughter, reflected in the need of a wider search for fewer whales.

The 1-Group of recovered marks contains eight returned after an average period of 375 days. Although the number is small and the tracks between the positions of marking and capture diverse, several points at once come to light. Three recoveries have been made on the South Georgia ground (Plate XLVIII) and two (Nos. 903, 3771) suggest that Blue whales return to this region from season to season, although, as explained above, little time is spent there during the season itself. The third of these recoveries (No. 10427/31) is of great interest, for the whale bearing these marks had come to South Georgia from the vicinity of Bouvet Island, a distance of 1180 miles, and with the former indicates an identity of stock over 40° of longitude. Another recovery (No. 3023), only 155 miles from the position of marking on the Enderby Land grounds, shows that the return to the same region may occur there as around South Georgia. This whale was among those marked between 22 January and 2 February 1935, as described above in the discussion of the 0-Group, and one cannot escape the suggestion that this particular whale was performing for a second time the westward movement from Enderby Land. On the other hand, two other Blue whales (Nos. 2816, 2892), marked about the same time in January 1935, were killed on the ground around 90° E. Thus there must be a considerable flow of Blue whales eastwards from Enderby Land, but, as it has already been shown that such a movement is apparently unusual during the season, it is presumably accomplished by an eastward movement during the southern winter and in lower latitudes. A third whale (No. 2026), marked a season later than the two above and in a position farther west, corroborates this movement and suggests that it may be a regular one from season to season. Although the disposition of the factory ships throughout several seasons suggests there are different and distinct whaling grounds off Enderby Land and about 90° E, off Queen Mary Land (*Hvalrådets Skrifter*, Nos. 7, 8, 9, 12, 14, 18), these recoveries demonstrate that Blue whales on the two grounds are of identical stock and move freely from one region to another.

The 2-Group whales further strengthen this view (Plate L). After an interval of two years whales are to be found on the same grounds (Nos. 2525, 5261), whether off Enderby Land or about 90° E. Also whales have moved during this period from the westerly ground to the easterly one (Nos. 3528, 5800). There is, however, as yet no evidence of a return movement from east to west.

The 3-Group is still negligible in number, only one whale (No. 2548) falling into this category, but this shows the persistent attractions of the original ground (Plate LI). Wherever this whale may have been during the 1100 days between marking and capture it may be considered to have returned to the area where it was marked, for only 470 miles separate the positions of marking and capture.

Marks from two Blue whales have been returned in the 4-Group, both from the Weddell Sea-South Georgia region (Plate LII), and they emphasize the conclusion drawn from the earlier groups; in fact, they show a remarkable similarity to the 1-Group in this area. One of these two whales (No. 1123/25) may be considered to demonstrate the return to the area of marking, for such movement as there is has been shown to take place during the course of a season. It is quite possible that this Blue whale actually passed close to South Georgia earlier in the season of its capture on its way to the position near the South Orkneys where it was taken. The second whale (No. 2537) extends the connexion between Bouvet Island and South Georgia shown by the movement of No. 10427/31 in the 1-Group. Mark No. 2537 was fired almost due south of the Cape of Good Hope, not very far from No. 2026; this mark, returned in the 1-Group, was recovered almost on 90° E. Marks Nos. 2537 and 2026 alone may be considered to show a general identity of Blue whale stocks between the grounds around South Georgia and those off Queen Mary Land.

MOVEMENTS OF FIN WHALES

As explained above, the number of Fin whales marked very greatly exceeds that of Blue whales, and the actual number of marks returned from Fin whales is much larger than the recoveries from Blues, although the percentage return is considerably smaller. The Blue whale is the chief quarry of the Antarctic whalers and is sought out by them in decided preference to Fins; especially has this been so since the commencement of pelagic fishing. Although the Fin whale is, away from the very edge of the pack-ice itself, usually far commoner, the catch of Blue whales in Antarctic waters has from 1927–28 to 1936–37 exceeded, and often greatly exceeded, that of Fin whales. In 1937–38 this position was markedly reversed, and although the number of Blue whales taken was even greater than in the previous season the Fin whale catch far exceeded that of any former season, doubling the highest preceding figure. In 1938–39 this figure was not maintained, but the Fin whale catch remained very high and well above that of Blue whales. It does seem, taking these two sets of facts together, that the Fin whale stock is, in comparison with the Blue whale stock, larger than the figures of the catches suggest, and possibly larger than has hitherto been realized. A total of 3915 Fin whales is estimated to have been marked, and of these 118 have been reported as captured (Table III).

TABLE III

Marked Fin whales killed in each group

Season of marking	Estimated number marked	Returned							
		Same season 0-Group	1st season 1-Group	2nd season 2-Group	3rd winter 2½-Group	3rd season 3-Group	4th season 4-Group	5th season 5-Group	6th season 6-Group
1932–33	202	3	2	—	—	—	2	—	—
1934–35	814	21	3	5	1	7	3		
1935–36	955	2	2	8	—	6			
1936–37	1251	5	18	8	—				
1937–38	683	13	9						
Totals	3905	44	34	21	1	13	5	—	—

Around South Georgia 1804 Fin whales have been marked by the hired whale-catchers operating from there, and sixty-six of these have been captured, seventeen the same season as they were marked. A large proportion of these Fin whales marked from South Georgia was found around the Shag Rocks, well over 600 having been marked there within a radius of seventy miles. Not one of these has been taken by the South Georgia whalers during the same season as marked. This clearly shows that the Fin whales passing the Shag Rocks during the time of the season when marking was accomplished have then no easterly component of any importance in their movement.

The time elapsing between the marking and capture of those Fin whales taken on the South Georgia grounds during the same season, the 0-Group, disregarding those whales taken the same day as marked, averages fifteen days and varies up to fifty-eight days. It is obvious, from the small number of returned marks compared with the large number of Fin whales marked in the neighbourhood of South Georgia, and the short average time between marking and capture, that the Fin whales do not remain in this region but, like Blue whales, are actually in transit when found in these grounds. On the other hand, their migration cannot be so direct and rapid as that of Blue whales, for whilst captured marked Blue whales only averaged six days on the grounds and only very few were taken, the average length of freedom of the captured marked Fin whales was fifteen days.

The movements of these marked Fin whales can only be described as erratic (Plate LIII). The whale (No. 1051) in this group, captured after the longest interval, fifty-eight days, had moved almost due south, whilst a second (No. 1006), taken after forty-four days, had moved almost due east. These two whales show over this period an average movement of little more than two miles a day, which strongly suggests that they had found food and stopped to enjoy it. Only during one season (1934–35) have whales marked west of the island been taken the same season by the South Georgia whalers. The positions of capture of two of these (Nos. 1051, 1322) are far from the whaling stations and suggest that whales at that time were scarce near the island so that a wide search was necessary. It would appear that Fin whales passing to the west of South Georgia enter very little into the catch normally made there.

Four Fin whales (Nos. 1081, 6554, 6609, 7036), marked near South Georgia, have been taken by the whaling fleet at the mouth of the Weddell Sea at distances from their place of marking of 626 to 765 miles (Plate LIV). Two (Nos. 6554, 6609), marked near the Shag Rocks, had travelled respectively south and south-west, and a third (No. 7036), marked east of South Georgia, had also moved south-south-west. These whales were marked in the season 1936–37, but the fourth, marked in an earlier season (1934–35), had moved almost south-east. This whale belonged to the same group, marked in the season 1934–35 between South Georgia and the Shag Rocks, as those taken east and north of South Georgia (Nos. 1006, 1051, 1322), and it is only from this season that there is any evidence of Fin whales, marked to the west of South Georgia, showing movement in easterly directions. During this season the catch of Fin whales made by the pelagic fleet in the Scotia Sea and at the mouth of the Weddell Sea was comparatively small.

In 1936–37, however, there is a strong indication that Fin whales tended to move from South Georgia rather west of south than east of south. We have seen how none of these whales approached South Georgia from the westward that season and how those whales taken far south had tended to move westwards. This is corroborated by the movement of factory ships. During this season factory ships lying to the south of South Georgia at the beginning of January moved westwards, whilst others from the east moved in to take their place. Considerable search for whales went on during this month between

0 and 50° W. In the next month, however, the move westwards continued, so that the whaling fleet in these waters became concentrated between 30 and 60° W. The catch of Blue whales in February decreased considerably, whilst that of Fin whales increased, so that the latter became the more important quarry. It seems unlikely that the region to the east of the South Sandwich Islands would have become so deserted if whales in quantity had been present there, and it thus appears probable that the considerable number of Fin whales that passed South Georgia and the Shag Rocks at the end of December and during January, when, as is obvious, there was no strong easterly movement, have continued on courses similar to those indicated by the captured marked whales (Nos. 6554, 6609, 7036), and may have provided the catch of almost 3000 Fin whales made in February and March between the South Sandwich and the South Shetlands Groups.

The 'William Scoresby's' work during the season 1937–38 was partly designed to investigate further this movement of Fin whales from South Georgia towards the Weddell Sea. Fin whales were marked during the first eleven days of January in the Scotia Sea between the South Sandwich Islands and the South Orkneys. Marks from ten of these whales were returned the same season after an average lapse of twenty-five days and after periods of six to fifty-four days. With one exception (No. 10826) they show movements between south and south-west. On 12 and 14 January more Fin whales were marked a little to the west of the South Orkneys. Three of these (Nos. 10903, 10946, 10949) were killed later in the season after an average lapse of forty-nine days and after periods between forty-five and fifty-four days. Without exception these whales show movements with direction between east and south-east. This suggests that here a second stream of whales may be flowing in from the west and, moving eastwards, passed the South Orkney Islands.

From the whaling grounds lying to the south of South Africa and extending eastwards to Enderby Land fourteen marked whales have been reported captured during the same season as they were marked. Of these, no details have been returned for two and a third was killed the same day as marked. The remaining eleven were taken after periods varying from 4 to 110 days and after an average lapse of twenty-six days. The whale (No. 2513) taken after the longest interval (110 days) shows a movement almost due south. It was marked on 1 December 1934 a little to the north of the pack-ice, and recovered on 20 March 1935 more than 900 miles farther south, when again it could not have been far from the pack-ice. Whatever courses it may have followed during the four months between marking and capture, its general movement has been to work southwards, apparently following the retreating ice-edge. The same general movement is shown by a second whale (No. 2077) marked in the middle of December of the following season in almost the same longitude, and recovered in February nearly 500 miles to the southward.

The direction of the movements of these two whales, as shown on the chart (Plate LIV), is the resultant of their movements during the course of the season. A third whale (No. 3300), however, marked in the same neighbourhood shows what may be the resultant direction during the latter part of the season. It was marked in February and recovered in March after forty-two days; in this time it had moved south-west. If this whale (No. 3300) demonstrates the general direction of movement made in the latter part of the period of freedom of the other two (Nos. 2513, 2077), these must have spent the earlier part of the season moving south-eastwards. That the movement during the latter part of the season is westerly is corroborated, to some extent, by the direction of movement of a whale (No. 8728) marked in February in a subsequent season and recovered after nineteen days, during which it had covered a distance of almost 300 miles in a west-north-westerly direction. The only other Fin whale (No. 3210) taken after a greater period than ten days moved, in twenty days, eighty-seven miles towards the south-south-east. Although this movement was made in the latter part of the season (February) and shows a distinct easterly direction the distance covered cannot be considered great enough to be very significant. The rest of the marked whales captured in this region and falling into the 0-Group were taken after short intervals of ten days or less and only show movement over short distances, in general towards the south.

The 1-Group of recovered Fin whales consists of thirty-four returns, one of which (No. 10515) records no data beyond that of recovery. The remaining thirty-three were taken after an average period of 384 days and after intervals varying from 306 to 483 days. The majority of these returns are from whales marked around South Georgia, and the striking thing about them is that with only two exceptions the distances between the position of marking and the position of capture fall within the limits of movements made by whales taken during the same season as marked in the 0-Group. The same applies to the whales marked off Enderby Land. Of the other whales in this group, those marked between Bouvet Island and the South Sandwich Islands, in the South Shetland Group and in the Bellingshausen Sea, no returns have been made the same season for comparison. These limited distances between the positions of marking and capture certainly indicate that Fin whales either remain in the same area of the Antarctic whaling grounds throughout the year or, after any migrations they may perform, normally return to the same area frequented during the preceding season. There can be little doubt that Fin whales usually forsake Antarctic waters for part of the year, so we can be reasonably confident that most of them make their return to the region previously visited. The two exceptions to this (Nos. 1233, 4091) were marked a little to the west of South Georgia in two successive seasons. Both were captured to the east, one (No. 1233) 553 miles almost due east of the position of marking, and the second (No. 4091) 1159 miles distant in an east-south-easterly direction. This latter whale was taken a little to the east of the meridian of Greenwich and may be regarded as already having passed into a region which has been considered to be apart from that around and to the south of South Georgia. Although most of the evidence shows that Fin whales return to the same region of the Antarctic they had formerly visited, here is a definite indication that this is not invariably so and that infiltration occurs between one region of abundance and another; from this it may be concluded that different and distinct races of Fin whales are not likely to be found in different areas of Antarctic waters. Though this infiltration from one region to the next may appear to be proceeding only very slowly it is doubtless sufficient to give the whole Fin whale population the uniform character it appears to possess.

Considering now the 1-Group Fin whales around South Georgia, two (Nos. 223, 248) taken in 1933–34 provided the first evidence that these whales remained in the same region or returned to the same region year by year (Plate LV). These two whales were marked in the initial experiment of 1932–33 on the same afternoon in the same large body of whales; they were killed within four days of each other and almost on the same position. This would appear to show that not only do Fin whales return to the same region from season to season, but that they often do so in the same company. A further six Fin whales (Nos. 6256, 6353, 6890, 6900, 6918, 7258), captured off the east coast of South Georgia, are some of the very large number marked within seventy miles of the Shag Rocks during the season 1936–37, none of which was taken that season on the South Georgia grounds. It seems that during the following season (1937–38) many of the whales that in the previous season had proceeded southwards, well to the west of South Georgia, now passed close to the island as though their southerly route had been shifted a little to the eastwards.

Eleven more of the Fin whales marked within seventy miles of the Shag Rocks during the season 1936–37 have been returned in the 1-Group from the factory ships working in the mouth of the Weddell Sea between the South Sandwich and the South Shetland Groups (Plate LVI). They demonstrate a similar movement to that followed by the 0-Group whales: from the position of marking in the vicinity of the Shag Rocks they spread in a fan-wise manner with the predominant direction south. If, however, this stream of movement is considered to have shifted to the east and to have flowed during the season past South Georgia rather than the Shag Rocks the predominant direction of movement would then be west of south. This direction would agree with the general direction of movement of those Fin whales marked by the 'William Scoresby' early in January 1938 in the southern part of the Scotia Sea and taken the same season (0-Group). Thus it seems probable that many of the whales marked then may have belonged to the same migratory stream as those marked the previous season around the Shag Rocks. That Fin whales were more abundant around South Georgia during the season 1937–38 than the previous season is shown by the catches made; this is especially so for January. There are thus considerable grounds for believing that the large stream of Fin whales which passed the Shag Rocks in the season of 1936–37 was, for some reason, deflected in 1937–38 so as to pass close to South Georgia itself. In such seasonal deflections of streams of migrating whales may be found the explanation of the periodical "Fin whale seasons" which characterize South Georgia whaling.

It is convenient now to consider the whales marked during the season 1937–38 and returned in the 1-Group; they are distinguished by having five-figure serial numbers. They are distributed from near Bouvet Island in the east to the Bellingshausen Sea in the west. With the exception of those marked in this westerly region, they do not greatly extend the distribution of the 1-Group recoveries in this region covering the mouth of the Weddell Sea, but they do add to the picture already built up here in that they show movements in a reverse direction to those already discussed. We already had in one whale (No. 4091) a link between South Georgia and the Greenwich meridian; but another (No. 10515/17) shows movement between the same regions, but from east to west. A similar case is that of a whale (No. 10240) marked in the South Shetlands and taken on the South Georgia grounds. Two whales (Nos. 10308, 10577) marked in the wide region between Bouvet Island and the South Sandwich Group have been recovered to the south-west and complement an earlier recovery (No. 1233). It is possible that the movements shown by these three whales (Nos. 10308, 10515/17, 10577) are very similar to those which might have been shown to take place during the course of a single season. The strong tendency to move westwards is noteworthy. Movements of the whaling fleet given in the *Hvalrådets Skrifter* (Nos. 3, 7, 8, 9, 12, 14, 18, 20) show, over several seasons including 1938–39 when these whales were taken, that the region between 0 and 20° W is forsaken towards the end of the season by the factory ships, as though the whales of this region had moved elsewhere. The whale (No. 10240) marked in the Bransfield Straits and recovered near South Georgia may have again been on its way to the South Shetlands, and, in fact, the track shown on the chart may easily have been that of movement during the season if the arrow indicating direction were reversed. This whale was captured very early in the season (6 December) and so had ample time to reach the South Shetlands if the opportunity had remained. A second whale (No. 11030) from near the South Shetlands has also identified itself with the Weddell Sea-South Georgia whales. This whale was one of a school of Fin whales numbering about twenty, most of which were marked one afternoon in the middle of January. They were very noticeable and distinctive even at that time of the year by their fatness and sluggish manner and in the possession of a very heavy and complete diatom film. How long they had been on their feeding grounds it is, of course, impossible to say, but they had every appearance of having already spent a considerable time in the Antarctic. It seems doubtful whether these whales moved eastwards, into the mouth of the Weddell Sea between 40 and 50° W that season, for none were captured, although very large numbers of Fin whales were taken there towards the end of the season, many of them inferior to and less attractive than these.

The appearance, at the mouth of the Weddell Sea, after twelve months, of Fin whales from the Bellingshausen Sea is of great interest. The identity of stock between the South Georgia-Weddell Sea grounds and the South Shetlands-Bellingshausen Sea grounds may be considered fully established. On the other hand, the recovery of these marks also strengthens the possibility of different streams of movement into the Weddell Sea region and supports the suggestion that in 1937–38 a stream of whales from the west reached the South Orkneys and beyond. The recognition of a close identity of stock over a wide area presents no difficulties, but the unravelling of a complex network of streams of movement or migration, many, doubtless, fusing and dividing, changing from season to season, is beyond the scope of whale-marking accomplished at present and many of the suggestions put forward in this paper must yet be looked upon as very tentative.

Although it is fully recognized that whale-marks can only be returned from those places where whaling is carried out and that the positions and movements of the factory ships have a considerable bearing on the picture rendered by the returned marks, it is also true that the factory ships do not remain long in areas where whales are not to be found. It does, therefore, seem reasonable to suggest that the part of the mouth of the Weddell Sea lying between 35 and 50° W has, for some reason, a strong attraction for Fin whales, which congregate there from a wide area extending to the east and west. In addition there seem to be strong grounds for considering the region between 30° W and 0° to be more sparsely populated with Fin whales. The reasons for this are obscure and a discussion of the possibilities beyond the scope of this paper, but it might be suggested that the influence of the submarine topography along the southern verge of the Scotia Sea on the hydrology of that region sets up conditions favouring the production of rich food stores which attract the whales.

On the grounds to the east, off Enderby Land, three returns (Nos. 2982, 3261, 5941) in this group show that here also Fin whales continue to frequent the same region from season to season.

The 2-Group of Fin whales is composed of twenty-one recoveries taken after intervals varying between 694 and 797 days and after an average lapse of 746 days. It is at once obvious that these recoveries reinforce very strongly the general outline of Fin whale movements deduced from the 1-Group returns (Plates LVII, LVIII). They show the return of Fin whales to the same region, and at times to the same locality, in which they were marked; and further, they show the infiltration between one region and another, a movement now on the whole more pronounced after a period of two years than after one year, a result naturally to be expected. One whale (No. 1034) shows how closely Fin whales on the South Georgia grounds will return to the same locality even after two years; three weeks later in the season than when marked it was captured twenty-two miles from its position of marking in 1934–35. Similarly, on the easterly grounds off Queen Mary Land a Fin whale (No. 5436) was taken a fortnight earlier in the season less than 200 miles from the marking position. Further, a number of whales marked near South Georgia and the Shag Rocks were returned from the pelagic grounds to the south and are, of course, returns from the same region, for their apparent movements are those demonstrated to take place during the course of a season. These whales were marked in three different seasons and they give the same picture as the 1-Group movements. There can be no doubt that many Fin whales normally return to the South Georgia-Shag Rocks-Weddell Sea region annually, though this cannot be regarded as a rigid rule.

The dispersal movement in the group is shown most clearly by whales marked on the Enderby Land grounds. Three whales (Nos. 5834, 5848, 5861), marked on the same day in March 1936 within a few miles of each other, all show a return to a position westwards of the marking position. Two (Nos. 5848, 5861) may be considered to have returned to the same grounds, the distances of the places of recovery from the marking position being 352 miles and 517 miles respectively, but the third (No. 5834) was taken 1150 miles away. The importance of this third recovery is to be found in considering its relationships with two whales (Nos. 4091, 10515/17) killed as members of the 1-Group. One of these (No. 4091) was marked near South Georgia some 2342 miles, almost 80° of longitude, distant from the position of marking of No. 5834; these two whales were killed on positions only 251 miles, actually less than 6° of longitude, apart. The third was marked in the same region where the other two were killed, but was captured in the mouth of the Weddell Sea. These recoveries may be considered to establish the intermingling of Fin whales over the wide area from Enderby Land to the Bellingshausen Sea. This intermingling is further illustrated by two whales (Nos. 2770/1, 2807) marked, again on the same day and position, off Enderby Land and captured far to the east on the grounds off Queen Mary Land. The distances between marking and recovery of these two are more than 1100 miles and more than 500 miles respectively. Thus, of five whales marked in a small area off Enderby Land and captured after two years, two show a divergence of 2223 miles and of 89° of longitude.

The 1-Group and the 2-Group recoveries provide connecting links between the Bellingshausen Sea and the whaling grounds off Queen Mary Land, over almost half the Antarctic periphery. These returned marks indicate the homogeneous character of the Antarctic Fin whale population over the whole region covered by the whaling fleets.

One Fin whale (No. 3482) marked in Antarctic waters has been taken in warmer regions to the north (Plate LIX). This whale was marked in February 1935 on 65° S; it was then noted to be a calf accompanying its mother. It was captured off Saldanha Bay, South Africa, on 1 July 1937, 1900 miles distant and almost due north of the position on which it was marked. The data returned with the mark gave this whale as a female 68 ft. 9 in. (20·97 m.) in length. No estimate was made of its length when marked, but it was then small enough to be confidently recorded as a calf accompanying a cow. This implies that its length then could not have been more than 40–45 ft., perhaps less, but not much less, for if it had been much under this length a note suggesting small size would certainly have been made. Accepting this estimate of the whale's length when marked, a length corresponding closely with that of 12 m. given by Mackintosh and Wheeler (1929) as the probable length of weaning in Fin whales, the whale shows a linear increase over the period of 862 days of 75 per cent. It may be confidently assumed that at the time of marking this whale was already several months old, and if this were so, the age of the whale when killed must have been about three years. Its length (20·97 m.) is a little more than that (20 m.) considered by Mackintosh and Wheeler (*loc. cit.*) to show the attainment of sexual maturity, which they suggest is normally reached after about two years. But this small excess is not inconsistent with an age of fully three years, for growth after the attainment of sexual maturity can be very slow and may even cease at a length not much exceeding the mean length at sexual maturity. On the other hand, if this whale had been new born at the time of marking its development would have corresponded very closely to the growth curve for female Fin whales given by Mackintosh and Wheeler (*loc. cit.*).

It is well known that the Fin whale fishery at Saldanha Bay is based on the capture of immature whales and the average length of Fin whales taken there during the season 1937 was 60·42 ft. (*International Whaling Statistics*), a length considerably less than that of this marked whale taken there. This whale draws further attention to the fact that in this locality the fishery is dependent upon Fin whales of an age less than three years.

The 3-Group consists of thirteen whales taken after periods between 1043 days and 1169 days and after an average period of 1098 days. The majority of these whales were marked around South Georgia, but returns of marks from whales marked off Enderby Land and Queen Mary Land are included. The general picture presented is very similar to that shown by the 2-Group discussed above (Plate LX). The whales marked around South Georgia and returned in this group show no greater dispersal than those of the 2-Group. There is a return to within a comparatively short distance of the position of marking in two cases (Nos. 1000, 1477). Three others (Nos. 1097, 1486, 4543), drawn from two different seasons, have been taken around the South Orkneys, suggesting a repetition in the third year of the seasonal movement southwards from South Georgia. The four other recoveries from South Georgia whales (Nos. 590, 842, 1443, 4368) are from the region lying between the South Sandwich Group and Bouvet Island and show a progressive dispersal across this region, which, it has been suggested, is not so attractive to Fin whales as that farther west. The three recoveries of marks from Enderby Land whales (Nos. 5784, 5818, 5997) all show movement to the west, but two (Nos. 5784, 5818) are so near the marking position that they only indicate a return to the same region. The third (No. 5997) has been recovered a considerable distance to the west and, it is interesting to note, overlaps the eastward movement of two of the South Georgia whales in this group, thus reproducing the picture given by the 2-Group whales. This region, lying about the Greenwich meridian, appears to be a meeting-place for South Georgia and Enderby Land whales. One whale (No. 5601) marked off Queen Mary Land has been recovered in this group, but in the same region and at a comparatively short distance from its marking position. These results, obtained from whales that have had three years of freedom, illustrate very markedly the strong instinct possessed by the Fin whale to return, perhaps season by season, to the same haunts—a trait that appears to be much stronger than the inclination to wander eastwards or westwards for great distances around the Antarctic.

Five Fin whales compose the 4-Group, taken after intervals between 1413 days and 1500 days and after an average period of 1461 days, exactly four years. These five returns epitomize completely the characteristic movements of Fin whales as shown by the "younger" groups (Plate LXI). There is the return to South Georgia by two (Nos. 235, 901) and there is the eastward dispersal movement from South Georgia (No. 484). This last one actually shows the longest movement from this region, having reached as far east as 10° E, more than 1500 miles, there to meet a whale (No. 2898) showing the westward movement from Enderby Land. There is no whale showing a return to the Enderby Land grounds, but a whale (No. 2679) has returned to within 515 miles of its position of marking on the Queen Mary Land grounds.

The main principles of the movements of Fin whales from season to season in those parts of the Antarctic seas where marking has taken place may be considered to be amply demonstrated by the data already to hand and discussed above. The characteristic movements are primarily a return to the same region and quite often to the same locality frequented the previous season, and secondly, a dispersal movement from these regions. This "dispersal" movement must, I think, be considered to affect fewer whales than the "return" movement, and it varies in strength from whale to whale, so that a false appearance of progressive movement is presented. Further, this dispersal movement appears to be limited in scope, the extreme movement after four years is little greater than the extreme movement after one year. This suggests the existence of larger self-contained provinces between which exchanges occur but slowly and within which whales usually return to their favourite haunts. One such province may be considered to extend from 0 to 75° W, the region embraced by the mouth of the Weddell Sea with an extension westwards into the Bellingshausen Sea. These provinces may draw their whales from a particular region of the world's oceans and in this region subtending as it does the South Atlantic, the whales may derive only from the Atlantic Ocean, excluding the eastern portion. The incompleteness and irregularity of whaling tend to render a biased view, but it is possible that dispersal movements may turn in definite directions; for example, there is, as yet, no westward movement shown from the far eastern grounds off Queen Mary Land.

MOVEMENTS OF HUMPBACK WHALES

The seasonal migrations of Humpback whales have long been known and recognized much more fully than those of other whale species, largely because these movements, in spring towards the Pole and in the autumn towards the Tropics, have appeared to be much more definite and regular than any of the known movements of other whales. The habits of Humpbacks of frequenting shallow waters and following coast-lines have enabled direct observations on this species to be made with greater ease and regularity. These habits, too, cause their wanderings to be more obviously canalized than those of the more exclusively oceanic species. This coast-frequenting habit has led to the establishment, at strategic points, of whaling stations, some of which have been in existence for long periods. These have enabled the migrations to be regularly observed and noted over many years. Such observations may be considered to have established a knowledge of the autumn south to north migration, for breeding purposes, along the coasts of New Zealand, Australia and South Africa and of the return journey towards the south in spring (Matthews, 1937). Actually, there has hitherto been very little direct evidence to support this before whale-marking yielded results. The return of marks from marked Humpback whales has at once given the most definite and most striking picture of the movements of this species and has confirmed in no uncertain manner some of the hitherto conjectured features of the migrations of the Humpback.

Coincident with the commencement of marking in 1934–35 there was a considerable increase in the importance of this species in the Antarctic catch; in that season the number of Humpbacks taken was more than double that of the previous season. This figure was almost doubled the following season (1935–36), in spite of new regulations imposing a lower length limit of 35 ft., and was subsequently increased the next season to the highest figure of 4477. The season 1937–38 saw a reduction in the numbers taken to less than half this figure, coincident with a phenomenally high Fin whale catch, perhaps indicating a neglect of the Humpback in favour of the larger quarry. The taking of Humpbacks by pelagic factories working south of 40° S latitude was totally prohibited by those countries who in June 1938 accepted the amendment to the international agreement of June 1937.

In addition to this great increase in the persecution of Humpback whales on the Antarctic grounds since 1934, increased toll has been taken of them in tropical waters. Whaling recommenced off the west coast of Australia in the southern winter of 1936 and more than 3000 Humpbacks were killed, a number which was increased the following year. Around Africa, whaling reopened off the Congo in the southern winter of 1934 and more than 700 Humpbacks were taken. This figure was almost doubled the following season, 1935, but since then there has been a rapid decline in the season's catch. At Saldanha Bay, whaling recommenced in 1936, but the catch of Humpbacks there has been trifling. Since 1935, when 418 whales were taken, the Humpback catch made off the Natal coast has shown a rapid and steady decline. A new ground off the southern coast of Madagascar was exploited by a factory ship in 1937 and 1223 Humpbacks taken; the following year the catch was increased to 1752. In 1935 whaling also recommenced along the west coast of South America and has since continued, but the catch of Humpbacks has been insignificant. This survey of the distribution and intensity of Humpback whaling is of interest in studying the returns of marks.

Of Humpbacks, 547 are estimated to have been effectively marked, and of these 540 were marked by the 'William Scoresby' on the Antarctic pelagic whaling grounds; the remaining seven have been marked around South Georgia. Of those marked by the 'William Scoresby' the majority were found on the most easterly grounds visited, between 80 and 110° E, where they were met with in considerable numbers. It is from the whales marked in this region that the largest number of recoveries have been made. A number of Humpbacks have also been marked to the westwards of Enderby Land, south of Africa, and in the Bellingshausen Sea.

Five whales constitute the 0-Group (Table IV), and these show only small movements. Of sixty-eight Humpbacks marked by the 'William Scoresby' in 1934–35, one (No. 3129/38) on the Enderby Land ground was recovered after five days a short distance to the south (Plate LXII). In 1935–36, one of four marked near South Georgia was captured after six days, and this showed a movement of 116 miles to the northward. In the following season, three whales marked off Queen Mary Land were captured after an average interval of twenty-one days. The distances traversed were small and were in directions to the south and south-east.

The most interesting recoveries of marks have been from those whales taken in the southern winter in warmer waters away from the Antarctic. The ½-Group contains eight returns, all from the north-west coast of Australia (Plate LXIII), but, it will be noticed, none from the marking of the season 1934–35, for whaling was not carried on off this coast in 1935. The following two seasons, 1936 and 1937, are both represented and include marks fired on the Antarctic grounds during the seasons 1935–36 and 1936–37. This evidence demonstrates clearly that the Humpbacks long known to pass along the west and north-west coasts of the Australian continent during the southern winter have actually come from the Antarctic seas between 80 and 100° E.

TABLE IV

Marked Humpback whales killed in each group

Season of marking	Estimated number marked	Returned						
		Same season 0-Group	1st winter ½-Group	1st season 1-Group	2nd winter 1½-Group	2nd season 2-Group	3rd winter 2½-Group	3rd season 3-Group
1932–33	2	—	—	—	—	—	—	—
1934–35	69	1	—	3	1	—	2	—
1935–36	204	1	6	2	8	—	2	1
1936–37	216	3	2	1	2	—	—	
1937–38	56	—	—	—	—			
Totals	547	5	8	6	11	—	4	1

Season of marking	Estimated number marked	Returned					
		4th winter 3½-Group	4th season 4-Group	5th winter 4½-Group	5th season 5-Group	6th winter 5½-Group	6th season 6-Group
1932–33	2	—	—	—	—	—	—
1934–35	69	1	—	—			
1935–36	204	—					
1936–37	216						
1937–38	56						
Totals	547	1	—	—	—	—	—

The 1-Group, which contains recoveries from five[1] whales, shows the return to the Antarctic grounds in the southern summer complementary to the northward movement shown by the ½-Group (Plate LXIV). The four recoveries on the Queen Mary Land ground after intervals varying between 330 and 393 days were all made at comparatively short distances from the position of marking. In this group there is also a single recovery to the south of Africa, and here the whale has been taken at a position quite near to where it had been marked.

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[1] Two marks (Nos. 2587, 2594) may be from the same whale; if not, the number of whales in this group is six.

The evidence of the northward migration to the north-west Australian coast from the Queen Mary Land ground shown by the ½-Group is repeated by the 1½-Group (Plate LXV), this time with ten recoveries situated between Dick Hartog's Island and North-West Cape. But another similar northward migration is disclosed by a recovery (No. 9326) off the south coast of Madagascar. This whale was marked well to the south of 60° S and about 10° E, and thus, in addition to the considerable movement northwards, there is also a fairly wide latitudinal movement.

It is curious that no Humpbacks have yet been taken after two years, but recoveries in the 2½-Group, four in all, have been made off the north-west Australian coast (Plate LXVI). The one recovery (No. 5509) in the 3-Group on the Queen Mary Land ground shows the persistent return to this region (Plate LXVII).

Although containing only one record (No. 2779) the 3½-Group is of special interest, for this recovery was also made on the whaling grounds off the southern point of Madagascar (Plate LXVIII). This whale had been marked quite close to Enderby Land and a considerable distance east of the other Madagascar recovery (No. 9326). It is possible that the Humpback whales found in the small region to the south of Madagascar are drawn from a much larger area of the Antarctic than those migrating to the north-west coast of Australia. It is noteworthy that no marked Humpback whale has been taken at Durban, where the catch is, however, smaller than on the Madagascar ground. It seems probable that the route followed by Humpbacks to and from the Antarctic may give Durban a wide berth and the whaling there may not tap the main stream of migration. There is no instance yet of latitudinal dispersal of Humpbacks from one region of abundance to another; in comparison with Blue and Fin whales the Humpback shows less initiative and seems content to follow the same routes, returning to the same region season after season. This is in agreement with the opinion hitherto held of its very regular migration and has enabled this species to be so heavily exploited in the past that some of the migratory streams have practically ceased, for example, that formerly passing South Georgia. The large provinces into which the Humpback stock might fall appear to be much more rigid and self-contained than those of the other species.

PERCENTAGE RETURN OF MARKS

The opinion has already been expressed that more marked whales are killed than are reported, for it is not to be expected that marks will invariably be found. Further, the numbers of whales given as effectively marked (Table I) are considered to be maximum figures, for some marks may be lost from these whales before capture. There may also be a wastage of marked whales through natural death or accidents. In the circumstances it is difficult to know exactly what value to place on the figures of percentage returns given in Table V, but these figures may be looked upon as reasonably reliable when considered relatively to each other, for the disturbing causes mentioned above must be acting more or less equally on the three species.

TABLE V

Percentages of marked whales killed

Species	No. marked	Returns	
		No.	%
Blue	668	33	4·94
Fin	3915	118	3·01
Humpback	548	36	6·59

The Blue whale is the species most eagerly sought after by the whalers, and the percentage figures show how the stock of Blue whales is being depleted at a considerably faster rate than that of Fins, 5 per cent of the marked Blue whales have been killed as opposed to 3 per cent of the marked Fin whales. When these figures are compared with the percentage of marked Humpbacks killed it is at once evident that the Humpback is being slaughtered at a surprisingly greater rate than either the Fin or the Blue; more than twice as fast as the Fin and much faster than the Blue. Marking has shown that the Humpback whales exploited off the north-west coast of Australia and off the south coast of Madagascar during the southern winter are the same as those upon which a toll has been levied only a few months previously in the Antarctic. The effect of this double persecution on what is quite a small total stock is well shown by the high percentage return of marks, indicating that the Humpback stock is suffering far more even than the Blue, which is itself, on other grounds, regarded as overtaxed (Laurie, 1937).

In this paper no attempt has been made to explain the impulses of whale movement which it may be possible to find, when further data are available, in such factors as food distribution, hydrological conditions, currents, bathymetrical features, and so on. The stream of Fin whales passing the Shag Rocks on their way southwards and their possible concentration in the western part of the mouth of the Weddell Sea in the latter part of the season may arise, as suggested earlier, from the form of the submarine ridges in these localities; the westward movement during the season of Blue whales from Enderby Land may have its origin in some current or ice disposition in this region, but at this stage even these tentative suggestions can hardly be made.

SUMMARY

1. Descriptions of the marks used and of the final successful form evolved are given.
2. Small alterations and additions made to the whale-marking craft and the methods of recording the results of shooting are described.
3. The scope and result of each whale-marking cruise and the method used to determine the number of whales marked are outlined.
4. The distribution of the whales marked is briefly discussed and diagrammatically depicted.

5. The manner in which marks are found and returned is explained.

6. The movements of whales as indicated by marking methods are discussed for Blue, Fin and Humpback whales, and these movements are shown on a series of charts illustrating the movements that had taken place after a given period of time.

7. Blue whales found around South Georgia are shown not to be a stationary population. Blue whales found off Enderby Land are demonstrated to move in a westerly direction during the latter part of the whaling season, and the movements of factory ships are considered to support this view.

Marks recovered after periods of one year and longer show that Blue whales return to the same region, but are also dispersed around the Antarctic Continent. This dispersal appears to be limited, for movements after four years have no greater amplitude than those after one year, but there is no evidence that Blue whales found in any one region of the area covered are segregated from the rest.

8. Fin whales found around South Georgia are shown not to be a stationary population, but they may loiter in the neighbourhood of the island longer than Blue whales. The movement from South Georgia during the whaling season is towards the south, and although large numbers of Fin whales pass close to the Shag Rocks none appears to move eastwards into the ambit of the South Georgia whalers. It is suggested that Fin whales pass southwards in this region on different tracks in different seasons. On other parts of the whaling grounds the direction of movement during the season appears to be generally to the south.

After one year Fin whales are shown to return very largely to the same area frequented the previous season, but a dispersal movement similar in many ways to that of Blue whales takes place. This dispersal movement provides connecting links between the Fin whales of the Bellinghausen Sea and those off Queen Mary Land. Fin whales originally found around the Shag Rocks may visit South Georgia.

These two movements of return and dispersal continue, but, as with Blue whales, dispersal is limited and not necessarily in itself progressive. In consequence, there appear to be large provinces between which very little interchange of Fin population takes place, but within which movement is considerable.

Migration from Antarctic waters to the Cape regions of South Africa has been shown to occur.

9. Humpback whales are shown to migrate, probably annually, from Antarctic waters to tropical regions off the north-west coast of Australia and off Madagascar. There is a return to the same region, but there appears to be no movement comparable to the dispersal demonstrated for the other two species; "provincial" stocks of Humpback whales are thus thought to be much more limited and self-contained than among Blues and Fins.

10. The percentage of marked whales killed shows that Humpback stocks are suffering very heavily in comparison with the other species because of recent expansions of Humpback whaling in tropical waters, and that the Blue whale stock is being depleted much faster than the Fin stock.

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NOTES ON THE TABLES

Table I (p. 252) shows the number of whales of each species effectively marked on each expedition. These numbers have been arrived at in the manner explained on p. 253. It should be understood that these numbers will probably change, for marks originally logged as misses etc. may be recovered, or two marks thought to be in different whales may be returned from the same whale; but these changes will be insignificant.

Table II (p. 258) gives the number of Blue whales killed in each group for each season's marking. The whales marked by the 'Discovery II' are omitted from this and the two following tables (III and IV). The total numbers of whales effectively marked during each season, the sum of the South Georgia and 'William Scoresby' marking, are given in the first column of figures. In the other columns are given the numbers of marked whales reported killed during the same season as they were marked and during each of the subsequent seasons. Table III (p. 261) and Table IV (p. 272) give the same data for Fin and Humpback whales respectively. Some of these whales have been taken in warm waters in the southern winters during the period between the Antarctic whaling seasons. These are the $\frac{1}{2}$-Groups.

Table V (p. 274) gives the numbers of Blue, Fin and Humpback whales effectively marked and the numbers of these killed in actual figures and as a percentage of the total marked.

Tables VI, VII and VIII (pp. 278–282) present a complete list of the returned marks for each species. The date and position of marking and the date and position of recovery are given. The marks are arranged in the groups corresponding with those in Tables II–IV. Within these groups they are arranged according to the season of marking, and for each season those marked around South Georgia from the whale-catcher precede those marked by the 'William Scoresby'. In each of these minor categories the marks are arranged numerically, and this gives almost complete numerical order for each group.

In one or two cases no data have been supplied with the returned marks; in others approximate dates and positions of recovery have been given, chiefly for marks returned from Humpbacks captured off the north-west coast of Australia. Where the position of capture has been given as the "N.W. coast of Australia" it has been considered to be "*ca.* 25° S, 113° E". Similarly, no exact position of marking for some whales marked in the vicinity of the Shag Rocks is available; for these, the actual position of the Shag Rocks, 53° 33′ S, 42° 02′ W, is given as the position of marking.

The length of time in days between marking and capture is given as "the period of freedom"; in calculating this the day of marking and the day of capture are both considered to be a complete day.

In those instances where two marks have been recovered from one whale, the two final digits of the number of the second mark are given after a stroke, it being understood that the preceding digits are the same as the corresponding digits of the accompanying mark. One exception occurs where the two marks are numbered 656 and 1229. This convention is also used in the text and on the charts.

TABLE VI

Marks returned from Blue whales

Mark no.	Date fired	Date recovered	Period of freedom days	Position fired	Position recovered
0-Group					
656/1229	26. xii. 34	29. xii. 34	4	54° 46′ S, 34° 00′ W 54° 40′ S, 33° 57′ W	54° 30′ S, 34° 19′ W
700	6. xii. 34	11. xii. 34	6	54° 15′ S, 33° 58′ W	54° 11′ S, 34° 50′ W
825/53	30. xi. 34	30. xi. 34	—	54° 55′ S, 35° 14′ W	55° 08′ S, 34° 32′ W
2902	22. i. 35	12. iii. 35	50	63° 32′ S, 47° 57′ E	*ca.* 66° S, 15° E
2903	22. i. 35	26. i. 35	5	63° 32′ S, 47° 57′ E	63° 56′ S, 45° 28′ E
2910	24. i. 35	26. i. 35	3	62° 45′ S, 46° 22′ E	63° 25′ S, 45° 56′ E
2960/65	26. i. 35	31. i. 35	6	62° 46′ S, 43° 05′ E	64° 46′ S, 41° 25′ E
2963	26. i. 35	8. ii. 35	14	62° 39′ S, 43° 58′ E	62° 39′ S, 34° 53′ E
2976	26. i. 35	14. ii. 35	20	62° 48′ S, 43° 04′ E	64° 16′ S, 35° 05′ E
3013	28. i. 35	27. iii. 35	59	61° 55′ S, 43° 17′ E	64° 14′ S, 29° 45′ E
3853	11. xii. 35	7. iii. 36	88	56° 08′ S, 36° 01′ W	63° 22′ S, 47° 07′ W
4122	27. xii. 35	30. xii. 35	4	57° 17′ S, 33° 55′ W	54° 34′ S, 33° 42′ W
4563	11. i. 36	11. ii. 36	32	55° 19′ S, 36° 39′ W	59° 44′ S, 29° 46′ W
4843	18. i. 36	22. i. 36	5	54° 52′ S, 33° 44′ W	55° 14′ S, 34° 15′ W
5245	1. ii. 36	8. ii. 36	8	62° 08′ S, 87° 37′ E	63° 55′ S, 87° 28′ E
5525	16. ii. 36	17. ii. 36	2	63° 15′ S, 94° 19′ E	63° 44′ S, 94° 25′ E
7705	13. xii. 36	9. ii. 37	59	54° 54′ S, 24° 49′ E	61° 07′ S, 20° 50′ E
10638	1. i. 38	9. i. 38	9	58° 48′ S, 31° 22′ W	61° 15′ S, 20° 21′ W
1-Group					
903	12. i. 35	19. i. 36	373	54° 01′ S, 38° 51′ W	55° 24′ S, 33° 47′ W
2816	17. i. 35	9. iii. 36	418	63° 21′ S, 53° 32′ E	*ca.* 64° S, 90° E
2892	22. i. 35	26. ii. 36	401	63° 31′ S, 47° 27′ E	65° 17′ S, 84° 30′ E
3023	28. i. 35	9. i. 36	347	62° 01′ S, 43° 21′ E	63° 37′ S, 39° 54′ E
3771	4. xii. 35	14. xi. 36	347	54° 11′ S, 39° 15′ W	54° 52′ S, 32° 41′ W
2026	14. xii. 35	16. xii. 36	369	57° 26′ S, 23° 50′ E	61° 00′ S, 87° E
5728	2. iii. 36	8. i. 37	313	63° 49′ S, 54° 24′ E	56° 48′ S, 17° 02′ E
10427/31	17. xii. 37	24. ii. 39	435	55° 49′ S, 00° 14′ W	55° 12′ S, 35° 24′ W
2-Group					
2525	5. xii. 34	1. ii. 37	790	56° 40′ S, 39° 00′ E	64° 33′ S, 22° 50′ E
3528	28. ii. 35	17. i. 37	690	63° 26′ S, 26° 11′ E	64° 27′ S, 79° 27′ E
5261	1. ii. 36	2. i. 38	702	61° 56′ S, 88° 42′ E	61° 52′ S, 82° 57′ E
5800	8. iii. 36	3. i. 38	667	64° 24′ S, 45° 49′ E	63° 14′ S, 72° 22′ E
3-Group					
2548	8. xii. 34	11. xii. 37	1100	58° 21′ S, 49° 16′ E	59° 00′ S, 34° 15′ E
4-Group					
1123/25	29. xii. 34	12. i. 39	1476	55° 00′ S, 34° 20′ W	62° 20′ S, 45° 50′ W
2537	4. xii. 34	22. xii. 38	1480	56° 36′ S, 35° 45′ E	57° 37′ S, 16° 28′ E

TABLE VII

Marks returned from Fin whales

Mark no.	Date fired	Date recovered	Period of freedom days	Position fired	Position recovered
0-Group					
41	20. xii. 32	27. xii. 32	8	53° 29′ S, 35° 40′ W	54° 21′ S, 35° 24′ W
206	28. xii. 32	3. i. 33	7	54° 41′ S, 34° 53′ W	54° 33′ S, 34° 54′ W
462/66	10. i. 33	20. i. 33	11	54° 02′ S, 37° 46′ W 54° 04′ S, 37° 46′ W	53° 49′ S, 38° 07′ W
597	2. xii. 34	2. xii. 34	—	53° 47′ S, 35° 08′ W	54° 11′ S, 34° 50′ W
609	5. xii. 34	Before 7. xii. 34	—	54° 31′ S, 34° 14′ W	South Georgia
840	30. xi. 34	Before 18. i. 35	—	55° 01′ S, 34° 31′ W	South Georgia
866	30. xi. 34	22. xii. 34	23	54° 49′ S, 34° 27′ W	53° 43′ S, 34° 31′ W
1006	13. i. 35	25. ii. 35	44	54° 05′ S, 39° 58′ W	53° 40′ S, 37° 00′ W
1051	17. xii. 34	12. ii. 35	58	53° 22′ S, 39° 32′ W	54° 38′ S, 39° 14′ W
1081	16. i. 35	31. iii. 35	75	53° 39′ S, 40° 07′ W	63° 28′ S, 28° 00′ W
1322	15. i. 35	18. i. 35	4	53° 54′ S, 39° 40′ W	53° 26′ S, 40° 15′ W
2433	1. xii. 34	1. xii. 34	—	54° 19′ S, 35° 50′ W	54° 10′ S, 34° 41′ W
2513	1. xii. 34	20. iii. 35	110	51° 01′ S, 29° 10′ E	66° 23′ S, 27° 08′ E
2724/25	14. i. 35	—	—	64° 17′ S, 56° 11′ E	—*
2750	16. i. 35	25. i. 35	10	63° 57′ S, 54° 27′ E	65° 13′ S, 50° 58′ E
2789	16. i. 35	21. i. 35	6	64° 00′ S, 54° 03′ E	64° 40′ S, 54° 50′ E
2797	16. i. 35	21. i. 35	6	64° 01′ S, 53° 57′ E	64° 25′ S, 54° 28′ E
2857/60	21. i. 35	21. i. 35	—	63° 57′ S, 48° 58′ E	64° 16′ S, 48° 55′ E
2876	21. i. 35	24. i. 35	4	63° 37′ S, 48° 23′ E	64° 03′ S, 48° 13′ E
3172/73	8. ii. 35	14. ii. 35	7	65° 49′ S, 29° 00′ E	64° 26′ S, 30° 47′ E
3192	10. ii. 35	16. ii. 35	7	63° 28′ S, 26° 54′ E	63° 38′ S, 28° 14′ E
3196	10. ii. 35	—	—	63° 28′ S, 26° 54′ E	—*
3210	10. ii. 35	1. iii. 35	20	63° 28′ S, 26° 54′ E	64° 43′ S, 28° 37′ E
3300	12. ii. 35	25. iii. 35	42	63° 13′ S, 22° 54′ E	67° 47′ S, 11° 37′ E
4132	27. xii. 35	5. i. 36	10	54° 17′ S, 33° 55′ W	54° 48′ S, 33° 33′ W
2077	16. xii. 35	6. ii. 36	53	56° 38′ S, 25° 25′ E	64° 37′ S, 28° 48′ E
6554	29. xii. 36	25. i. 37	28	53° 24′ S, 41° 32′ W	64° 26′ S, 45° 51′ W
6609	30. xii. 36	7. iii. 37	68	52° 58′ S, 41° 56′ W	64° 30′ S, 52° 30′ W
6628	3. i. 37	4. i. 37	2	54° 26′ S, 34° 14′ W	54° 48′ S, 34° 28′ W
7036	21. i. 37	16. ii. 37	27	54° 38′ S, 30° 54′ W	64° 15′ S, 38° 56′ W
8728	13. ii. 37	3. iii. 37	19	64° 41′ S, 30° 16′ E	62° 45′ S, 20° 22′ E
10679	2. i. 38	24. i. 38	23	59° 17′ S, 32° 30′ W	62° 29′ S, 34° 13′ W
10723	7. i. 38	3. ii. 38	28	59° 22′ S, 33° 00′ W	63° 44′ S, 39° 53′ W
10728	7. i. 38	18. i. 38	12	59° 22′ S, 33° 04′ W	61° 30′ S, 40° 30′ W
10762	9. i. 38	19. i. 38	11	59° 33′ S, 38° 51′ W	62° 06′ S, 41° 11′ W
10765	9. i. 38	24. i. 38	16	59° 33′ S, 38° 51′ W	62° 25′ S, 41° 59′ W
10776	9. i. 38	3. iii. 38	54	59° 33′ S, 38° 53′ W	61° 26′ S, 50° 05′ W
10826	10. i. 38	11. ii. 38	33	59° 57′ S, 40° 36′ W	63° 51′ S, 39° 20′ W
10881	11. i. 38	10. ii. 38	31	59° 55′ S, 41° 42′ W	63° 27′ S, 45° 02′ W
10882	11. i. 38	13. ii. 38	34	59° 55′ S, 41° 42′ W	62° 57′ S, 43° 29′ W
10883	11. i. 38	16. i. 38	6	59° 55′ S, 41° 42′ W	60° 50′ S, 42° 00′ W
10903	12. i. 38	6. iii. 38	54	60° 02′ S, 46° 46′ W	63° 12′ S, 40° 11′ W
10946	14. i. 38	27. ii. 38	45	61° 06′ S, 47° 19′ W	62° 34′ S, 40° 33′ W
10949	14. i. 38	1. iii. 38	47	61° 06′ S, 47° 19′ W	61° 30′ S, 43° 30′ W

* No other details available.

TABLE VII *Marks returned from Fin whales (continued)*

Mark no.	Date fired	Date recovered	Period of freedom days	Position fired	Position recovered
1-Group					
223	28. xii. 32	27. i. 34	396	54° 41′ S, 34° 53′ W	53° 59′ S, 36° 13′ W
248	28. xii. 32	31. i. 34	400	54° 41′ S, 34° 53′ W	54° 02′ S, 36° 17′ W
1233	26. xii. 34	4. xii. 35	344	54° 44′ S, 33° 59′ W	56° 28′ S, 17° 58′ W
2982	27. i. 35	29. i. 36	368	62° 27′ S, 42° 49′ E	62° 20′ S, 40° 13′ E
3261	11. ii. 35	27. ii. 36	382	63° 33′ S, 24° 06′ E	68° 15′ S, 16° 00′ E
4091	27. xii. 35	20. i. 37	391	54° 16′ S, 34° 04′ W	60° 00′ S, 00° 24′ E
5941	17. iii. 36	16/19. i. 37	306/9	64° 08′ S, 29° 49′ E	*ca.* 62° 20′ S, 25° 40′ E
6211	13. xii. 36	23. xii. 37	376	54° 29′ S, 41° 19′ W	60° 53′ S, 37° 30′ W
6252	14. xii. 36	15. iii. 38	457	53° 33′ S, 42° 02′ W	61° 14′ S, 30° 10′ W
6256	14. xii. 36	10. iv. 38	483	53° 33′ S, 42° 02′ W	*ca.* 54° 20′ S, 36° 10′ W
6308	14. xii. 36	12. ii. 38	426	53° 33′ S, 42° 02′ W	63° 20′ S, 40° 00′ W
6353	15. xii. 36	14. i. 38	396	53° 33′ S, 42° 02′ W	54° 07′ S, 36° 21′ W
6371	15. xii. 36	28. ii. 38	441	53° 33′ S, 42° 02′ W	62° 33′ S, 43° 57′ W
6427	15. xii. 36	27. ii. 38	440	53° 33′ S, 42° 02′ W	62° 30′ S, 44° 00′ W
6473	27. xii. 36	1. i. 38	371	53° 32′ S, 40° 55′ W	60° 58′ S, 41° 14′ W
6597	30. xii. 36	16. ii. 38	414	53° 00′ S, 41° 42′ W	63° 21′ S, 39° 17′ W
6810	9. i. 37	12. i. 38	369	53° 36′ S, 42° 34′ W	61° 35′ S, 45° 10′ W
6819	9. i. 37	19. i. 38	376	53° 36′ S, 42° 34′ W	62° 06′ S, 41° 11′ W
6890	11. i. 37	4. ii. 38	390	53° 32′ S, 40° 38′ W	54° 48′ S, 35° 17′ W
6900	11. i. 37	26. i. 38	381	53° 32′ S, 40° 38′ W	54° 29′ S, 34° 59′ W
6915	11. i. 37	7. ii. 38	393	53° 32′ S, 40° 38′ W	63° 41′ S, 39° 48′ W
6918	11. i. 37	4. ii. 38	390	53° 32′ S, 40° 38′ W	54° 42′ S, 35° 09′ W
6946	11. i. 37	Before 18. iii. 38	—	53° 32′ S, 40° 38′ W	*ca.* 61° 00′ S, 53° 30′ W
7002/32	21. i. 37	21. xii. 37	335	54° 38′ S, 30° 54′ W	53° 43′ S, 35° 10′ W
7258	30. i. 37	24. i. 38	360	53° 23′ S, 42° 20′ W	54° 25′ S, 34° 58′ W
10240	4. ii. 38	6. xii. 38	306	62° 37′ S, 58° 54′ W	53° 30′ S, 30° 10′ W
10308	26. xi. 37	24. xii. 38	394	57° 28′ S, 22° 41′ W	59° 04′ S, 38° 00′ W
10515	21. xii. 37	1938/39	—	54° 48′ S, 00° 48′ W	—
10517	21. xii. 37	5. iii. 39	430	54° 48′ S, 00° 48′ W	63° 46′ S, 40° 22′ W
10577	24. xii. 37	6. iii. 39	438	57° 36′ S, 11° 46′ W	64° 24′ S, 21° 37′ W
11014/15	17. i. 38	4. ii. 39	384	61° 18′ S, 49° 58′ W	62° 31′ S, 46° 33′ W
11030	19. i. 38	22. ii. 39	400	61° 20′ S, 61° 03′ W	65° 09′ S, 40° 42′ W
11075	23. i. 38	3. ii. 39	377	68° 02′ S, 77° 56′ W	62° 23′ S, 44° 13′ W
11106	30. i. 38	27. i. 39	363	66° 10′ S, 73° 21′ W	61° 58′ S, 37° 21′ W
2-Group					
1001	13. i. 35	1. iii. 37	779	54° 03′ S, 39° 24′ W	62° 19′ S, 36° 33′ W
1034	13. i. 35	3. ii. 37	753	54° 03′ S, 39° 24′ W	53° 54′ S, 38° 48′ W
1167	29. xii. 34	28. ii. 37	793	55° 09′ S, 33° 58′ W	62° 08′ S, 35° 45′ W
2770/71	16. i. 35	22. ii. 37	769	64° 00′ S, 54° 03′ E	62° 55′ S, 95° 09′ E
2807	16. i. 35	5. i. 37	721	64° 02′ S, 54° 00′ E	61° 54′ S, 72° 07′ E
4416	4. i. 36	11. xii. 37	708	55° 39′ S, 32° 18′ W	60° 58′ S, 34° 56′ W
4438	6. i. 36	23. i. 38	749	55° 39′ S, 32° 18′ W	61° 18′ S, 20° 20′ W
4661	13. i. 36	14. xii. 37	702	55° 28′ S, 33° 51′ W	61° 08′ S, 35° 56′ W
4669	13. i. 36	22. ii. 38	771	55° 28′ S, 33° 51′ W	62° 23′ S, 18° 15′ W
5436	11. ii. 36	27. i. 38	717	64° 27′ S, 104° 04′ E	63° 02′ S, 110° 43′ E
5834	9. iii. 36	3. iii. 38	725	64° 10′ S, 45° 29′ E	63° 10′ S, 06° 10′ E
5848	9. iii. 36	2. iii. 38	724	64° 10′ S, 45° 29′ E	60° 32′ S, 35° 30′ E
5861	9. iii. 36	7. iii. 38	729	64° 03′ S, 45° 17′ E	68° 49′ S, 27° 16′ E
6324	15. xii. 36	19. ii. 39	797	53° 33′ S, 42° 02′ W	61° 58′ S, 48° 47′ W
6389	15. xii. 36	11. i. 39	758	53° 33′ S, 42° 02′ W	61° 37′ S, 54° 15′ W
6480	27. xii. 36	20. xi. 38	694	53° 32′ S, 40° 55′ W	South Georgia
6522/61	28/29. xii. 36	12. ii. 39	757/756	*ca.* 53° 27′ S, 41° 39′ W	61° 32′ S, 49° 26′ W
6530	28. xii. 36	15. ii. 39	760	*ca.* 53° 27′ S, 41° 39′ W	63° 18′ S, 45° 12′ W
6877	11. i. 37	13. i. 39	733	53° 32′ S, 40° 38′ W	*ca.* 55° 09′ S, 35° 04′ W
6935	11. i. 37	16. ii. 39	767	53° 31′ S, 40° 39′ W	63° 54′ S, 45° 13′ W
6968	11. i. 37	10. ii. 39	761	53° 31′ S, 40° 39′ W	63° 34′ S, 41° 07′ W

TABLE VII (*continued*)

Marks returned from Fin Whales

Mark no.	Date fired	Date recovered	Period of freedom days	Position fired	Position recovered
2½-Group					
3482	24. ii. 35	30. vi. 37	862	64° 52′ S, 22° 30′ E	*ca.* 33° 04′ S, 17° 50′ E
3-Group					
590	5. xii. 34	15. ii. 38	1169	54° 34′ S, 34° 21′ W	61° 57′ S, 16° 28′ W
842	29. xi. 34	23. i. 38	1152	54° 55′ S, 35° 14′ W	57° 47′ S, 11° 18′ W
1000	13. i. 35	29. xii. 37	1082	54° 05′ S, 39° 58′ W	53° 54′ S, 35° 09′ W
1097	15. i. 35	13. i. 38	1095	53° 54′ S, 39° 40′ W	61° 01′ S, 41° 27′ W
1443	25. i. 35	16. i. 38	1088	54° 45′ S, 40° 50′ W	60° 42′ S, 23° 13′ W
1477	25. i. 35	17. i. 38	1089	54° 06′ S, 40° 23′ W	53° 59′ S, 35° 22′ W
1486	25. i. 35	12. ii. 38	1115	54° 06′ S, 40° 23′ W	63° 09′ S, 43° 46′ W
4368	4. i. 36	24. i. 39	1117	55° 39′ S, 32° 18′ W	62° 09′ S, 03° 49′ W
4543	11. i. 36	9. ii. 39	1126	55° 19′ S, 36° 39′ W	61° 36′ S, 49° 18′ W
5601	19. ii. 36	27. xii. 38	1043	63° 27′ S, 90° 19′ E	64° 21′ S, 106° 22′ E
5784	8. iii. 36	3. ii. 39	1063	64° 42′ S, 46° 32′ E	64–66° S, 31–35° E
5818	9. iii. 36	6. iii. 39	1093	64° 14′ S, 45° 23′ E	65° 27′ S, 28° 09′ E
5997	19. iii. 36	31. i. 39	1049	64° 25′ S, 23° 10′ E	60° 48′ S, 11° 10′ W
4-Group					
235	28. xii. 32	10. xii. 36	1444	54° 41′ S, 34° 53′ W	53° 52′ S, 40° 16′ W
484	11. i. 33	16. ii. 37	1498	54° 11′ S, 38° 06′ W	57° 49′ S, 09° 05′ E
901	2. i. 35	23. xii. 38	1452	53° 47′ S, 38° 42′ W	54° 31′ S, 34° 00′ W
2898	22. i. 35	1. iii. 39	1500	63° 30′ S, 47° 37′ E	61° 05′ S, 10° 05′ E
2679	30. xii. 34	11. i. 39	1413	60° 40′ S, 92° 50′ E	63° 33′ S, 110° 07′ E

TABLE VIII

Marks returned from Humpback whales

Mark no.	Date fired	Date recovered	Period of freedom days	Position fired	Position recovered
0-Group					
3129/38	4. ii. 35	8. ii. 35	5	61° 54′ S, 34° 44′ E	62° 39′ S, 34° 53′ E
4652	13. i. 36	18. i. 36	6	55° 26′ S, 34° 13′ W	53° 37′ S, 35° 22′ W
8295	23. i. 37	17. ii. 37	26	60° 25′ S, 96° 16′ E	63° 13′ S, 95° 59′ E
8426	26. i. 37	11. ii. 37	17	62° 42′ S, 88° 47′ E	63° 55′ S, 93° 56′ E
8427	26. i. 37	15. ii. 37	21	62° 42′ S, 88° 47′ E	63° 59′ S, 92° 48′ E
½-Group					
5307	2. ii. 36	Winter 1936	—	62° 26′ S, 90° 03′ E	*ca.* 25° S, 113° E
5319	5. ii. 36	vii. 36	—	63° 38′ S, 93° 20′ E	22° 49′ S, 113° 33′ E
5360	6. ii. 36	29. viii. 36	206	62° 42′ S, 95° 55′ E	21° 27′ S, 114° 15′ E
5403	8. ii. 36	20. vii. 36	164	61° 25′ S, 98° 54′ E	24° 24′ S, 113° 12′ E
5555	17. ii. 36	Winter 1936	—	63° 51′ S, 92° 21′ E	*ca.* 25° S, 113° E
5566	18. ii. 36	Winter 1936	—	63° 28′ S, 91° 04′ E	*ca.* 25° S, 113° E
8052	8. i. 37	Winter 1937	—	63° 00′ S, 74° 50′ E	*ca.* 25° S, 113° E
8260	23. i. 37	21. viii. 37	211	60° 34′ S, 95° 59′ E	25° 15′ S, 113° 09′ E
1-Group					
2587*	22. xii. 34	23. xii. 35	367	60° 07′ S, 94° 32′ E	60° 51′ S, 87° 25′ E
2594*	22. xii. 34	23. xii. 35	367	60° 07′ S, 94° 32′ E	60° 51′ S, 87° 25′ E
2657	29. xii. 34	26. xii. 35	363	60° 37′ S, 96° 48′ E	60° 33′ S, 89° 09′ E
2024	13. xii. 35	2. i. 37	387	57° 22′ S, 23° 28′ E	*ca.* 55° S, 29° E
5298	2. ii. 36	27. xii. 36	330	62° 14′ S, 89° 35′ E	61° 00′ S, 86° 00′ E
8322	24. i. 37	20. ii. 38	393	60° 08′ S, 96° 56′ E	63° 00′ S, 90° 17′ E
1½-Group					
2639	28. xii. 34	15. viii. 36	597	60° 45′ S, 97° 06′ E	21° 37′ S, 114° 15′ E
5200	30. i. 36	18/19. viii. 37	567/8	61° 00′ S, 90° 32′ E	24° 55′ S, 113° 07′ E
5206/11	30. i. 36	*ca.* 24. viii. 37	*ca.* 573	61° 09′ S, 90° 18′ E	25° 35′ S, 113° 03′ E
5213	30. i. 36	Winter 1937	—	61° 09′ S, 90° 18′ E	*ca.* 25° S, 113° E
5240	31. i. 36	6. viii. 37	554	62° 19′ S, 88° 46′ E	24° 57′ S, 113° 12′ E
5333	5. ii. 36	28. vi. 37	510	63° 01′ S, 94° 42′ E	*ca.* 25° S, 113° E
5385	8. ii. 36	Winter 1937	—	61° 37′ S, 98° 42′ E	*ca.* 24° 51′ S, 113° 15′ E
5413	9. ii. 36	Winter 1937	—	62° 19′ S, 102° 16′ E	*ca.* 25° S, 113° E
5593	18. ii. 36	Winter 1937	—	63° 20′ S, 90° 17′ E	*ca.* 25° S, 113° E
8220	22. i. 37	16. viii. 38	572	61° 10′ S, 94° 50′ E	*ca.* 25° S, 113° E
9326	14. iii. 37	17. viii. 38	522	62° 18′ S, 10° 41′ E	25° 36′ S, 44° 52′ E
2½-Group					
2610	23. xii. 34	23. ix. 37	975	60° 06′ S, 95° 46′ E	25° 00′ S, 113° 10′ E
2678	1. i. 35	17. vii. 37	913	60° 29′ S, 85° 09′ E	22° 40′ S, 113° 30′ E
5174	30. i. 36	Winter 1938	—	60° 55′ S, 90° 40′ E	*ca.* 25° S, 113° E
5558	17. ii. 36	17. ix. 38	926	63° 51′ S, 92° 21′ E	24° 55′ S, 113° 07′ E
3-Group					
5509	14. ii. 36	10. xi. 38	1002	63° 39′ S, 98° 04′ E	58° 29′ S, 100° 23′ E
3½-Group					
2779	16. i. 35	24. viii. 38	1217	64° 00′ S, 54° 03′ E	25° 03′ S, 47° 10′ E

* May be same whale.

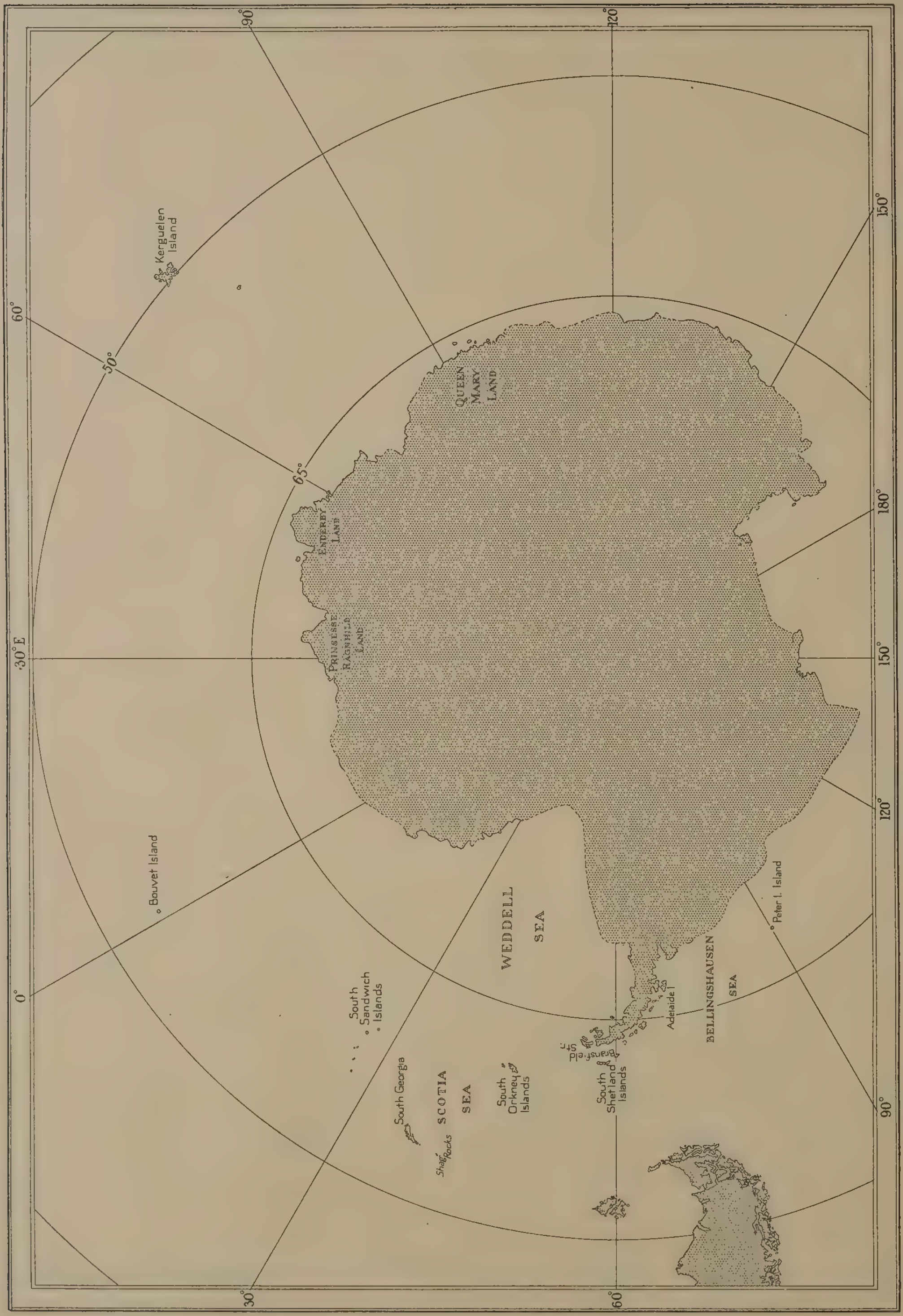
NOTES ON THE CHARTS

Plates XLIII, XLIV are key charts covering the whole area with which this paper is concerned; they give all the names mentioned in the text.

Plate XLV offers a schematic representation of the distribution of marked whales. A full explanation is given on p. 254.

Plates XLVI–LII show the movements of marked Blue whales in each group; similarly Plates LIII–LXI and Plates LXII–LXVIII show the movements of Fin and Humpback whales respectively. On these charts the position of marking is shown by an open circle and the position of capture is indicated by a closed circle.

Plates XLVI, XLVIII, LIII, LV, LVII show the movements of marked whales on the South Georgia grounds, the tracks of marked whales captured beyond the boundaries of these charts are also shown. A circle of 70 miles radius is drawn around the Shag Rocks.


90°
120°
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50°
65°
30° E
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180°
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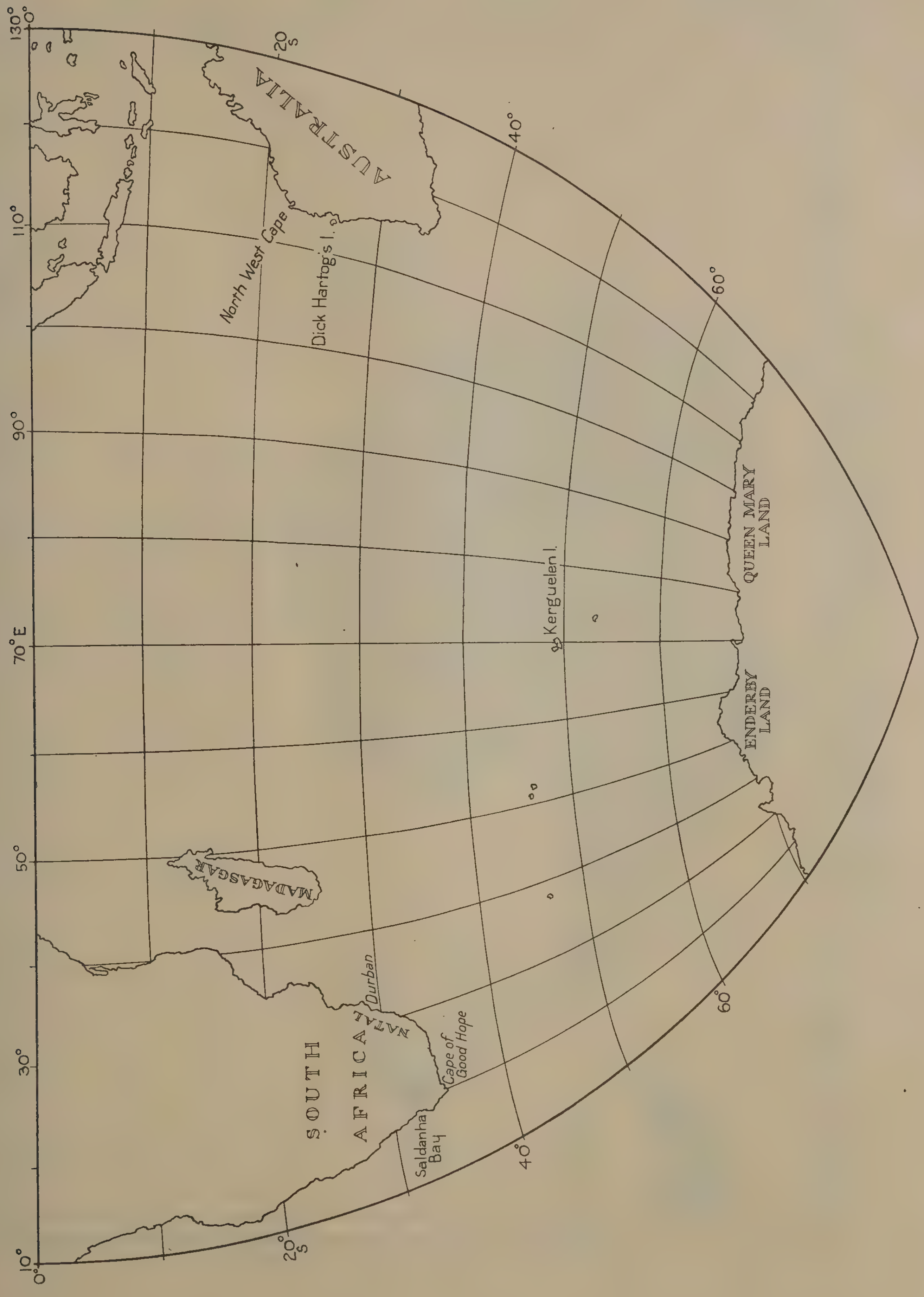
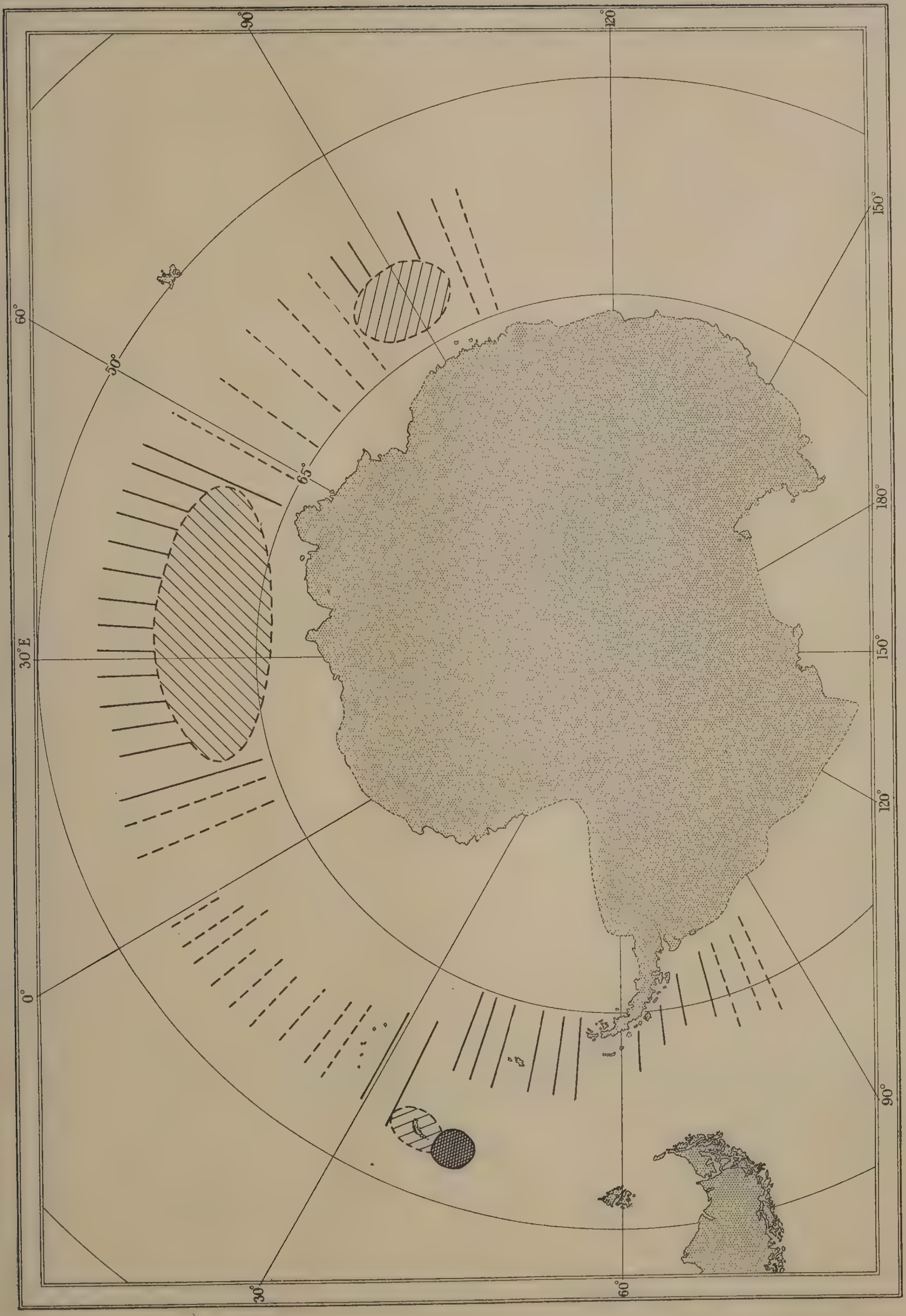
90°
30°
60°
Kerguelen Island
Bouvet Island
QUEEN MARY LAND
ENDERBY LAND
PRINSESSE RAGNHILD LAND
WEDDELL SEA
South Sandwich Islands
South Georgia
Shag Rocks
SCOTIA SEA
South Orkney Islands
South Shetland Islands
Bransfield Str.
Adelaide I.
BELLINGSHAUSEN SEA
Peter I. Island

Key chart of Southern Ocean whaling grounds.


130°
0°
20° S
AUSTRALIA
40°
North West Cape
Dick Hartog's I.
110°
60°
90°
QUEEN MARY LAND
Kerguelen I.
70° E
ENDERBY LAND
50°
MADAGASCAR
Durban
NATAL
SOUTH AFRICA
Cape of Good Hope
60°
30°
Saldanha Bay
40°
20° S
10°
0°

Key chart of Indian Ocean whaling grounds.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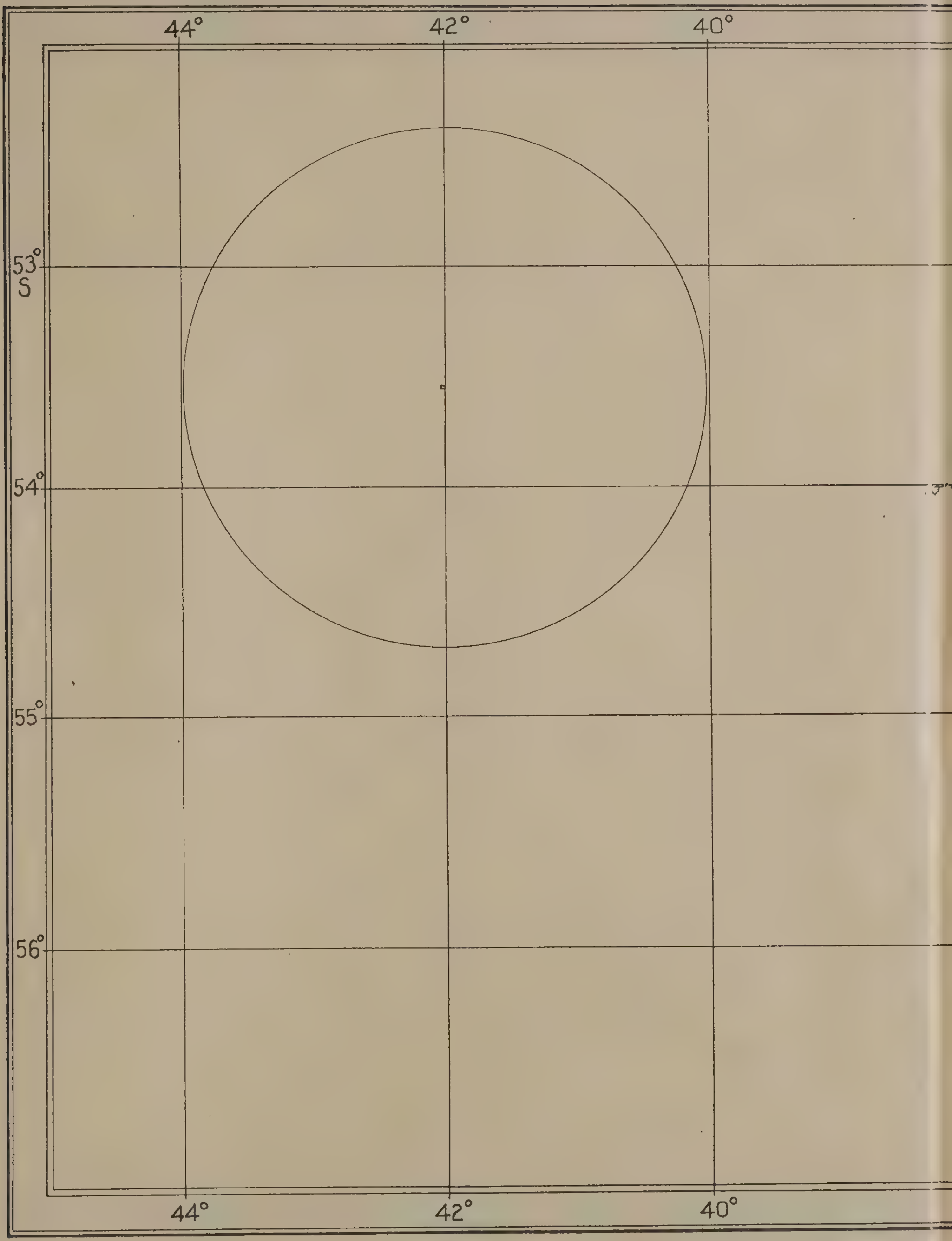
0°
90°
30°
60°

Chart illustrating schematically the distribution of marked whales (see p. 254).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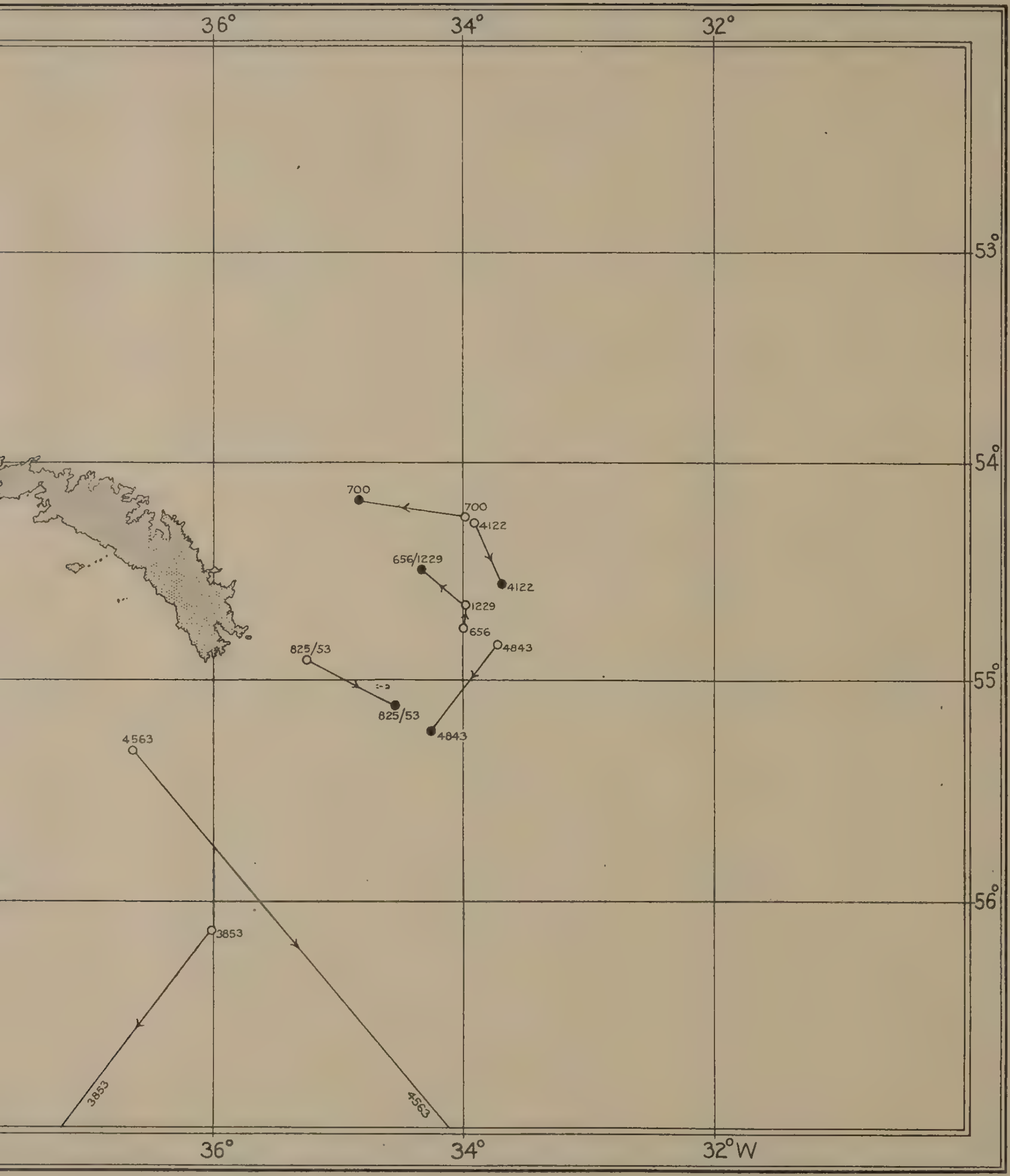
Blue whales. South Georgia. F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32°
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56°
700
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4122
4122
656/1229
1229
656
825/53
825/53
4843
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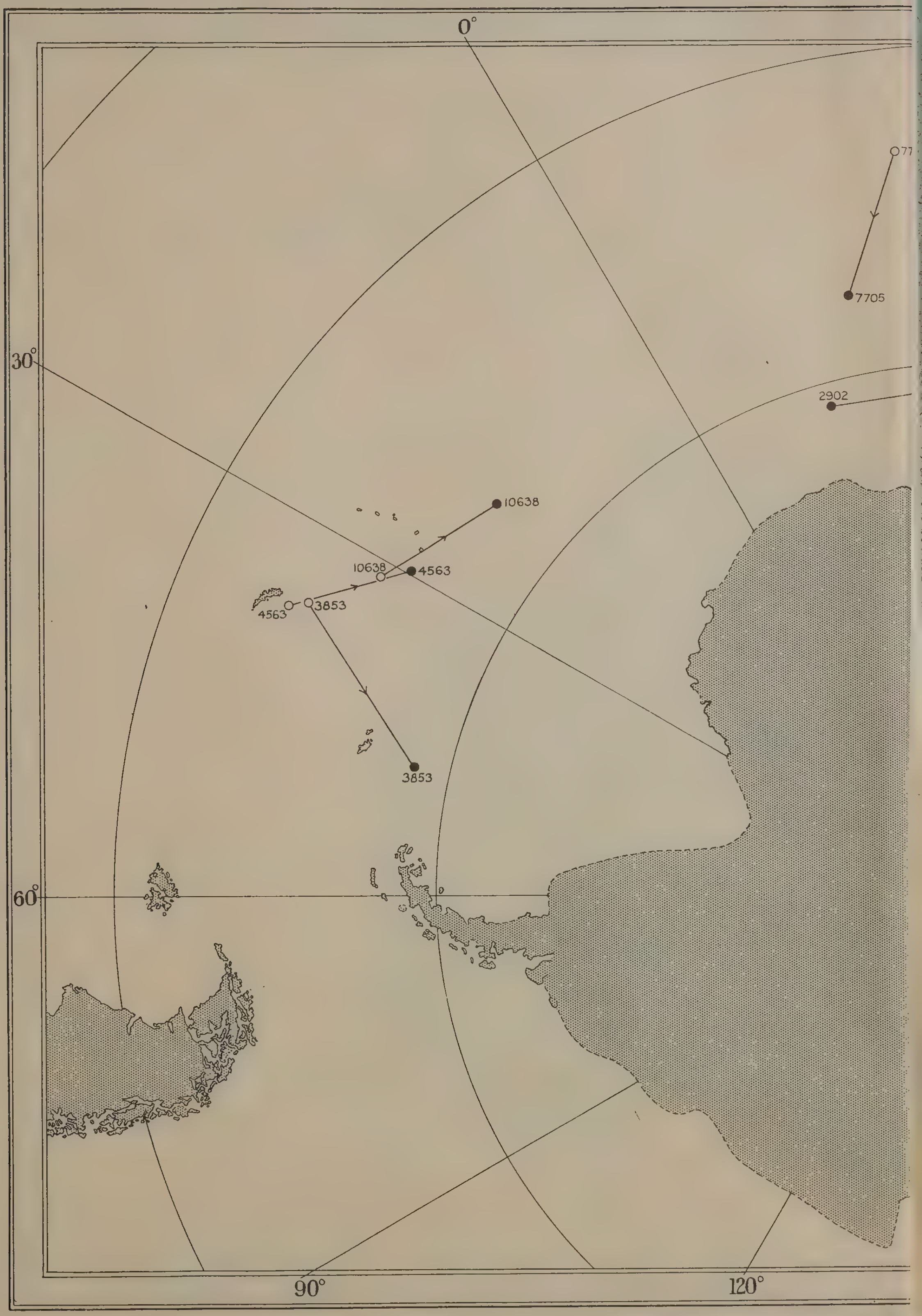
4563
3853
3853
4563
36°
34°
32°W

s of marking and capture of 0-group whales.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10638
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4563
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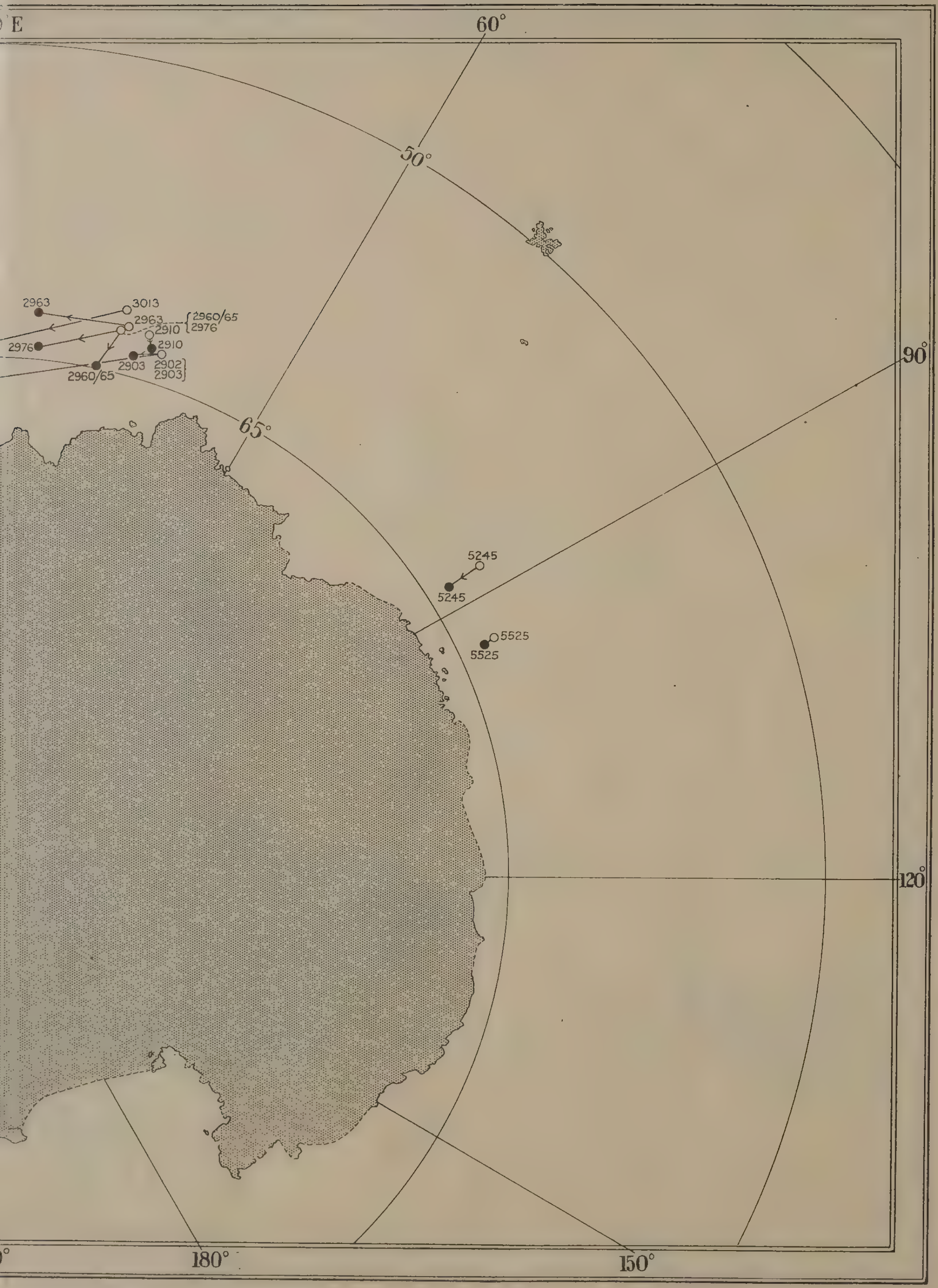
Blue whales. Southern Ocean. Pos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2902
2903
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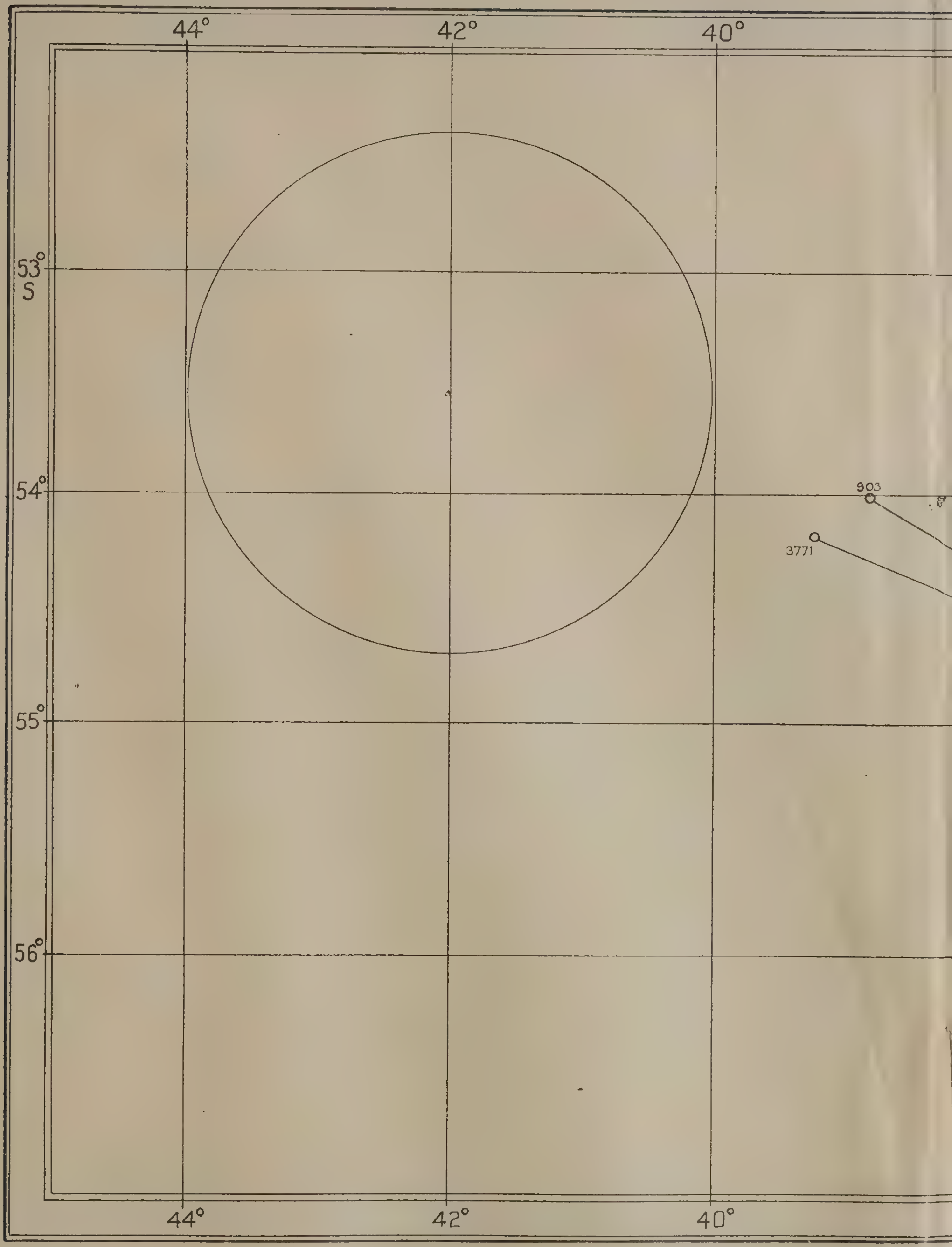
5245
5245
5525
5525

marking and capture of o-group whales.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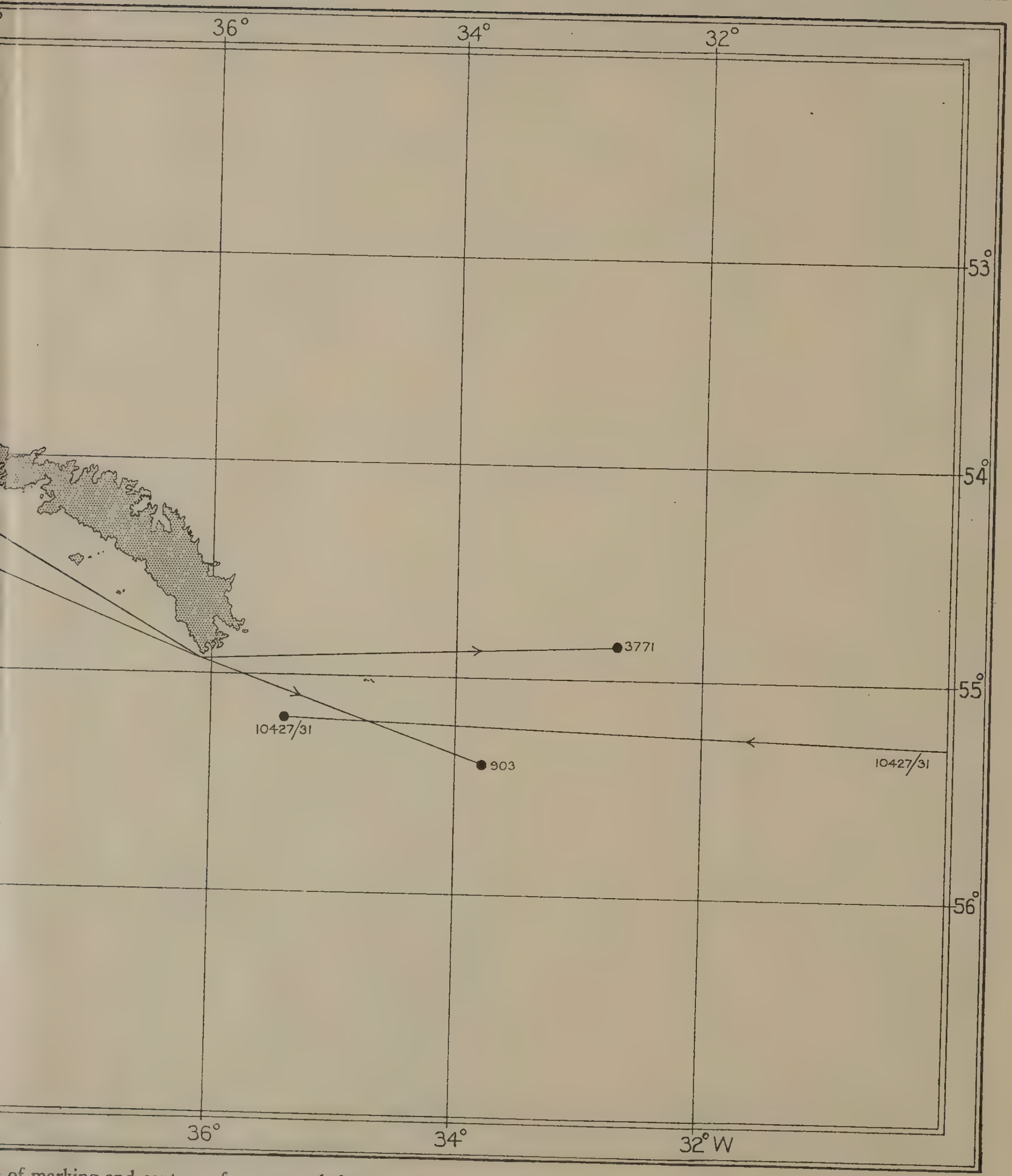
Blue whales. South Georgia. P

PLATE XLVIII


36°
34°
32°
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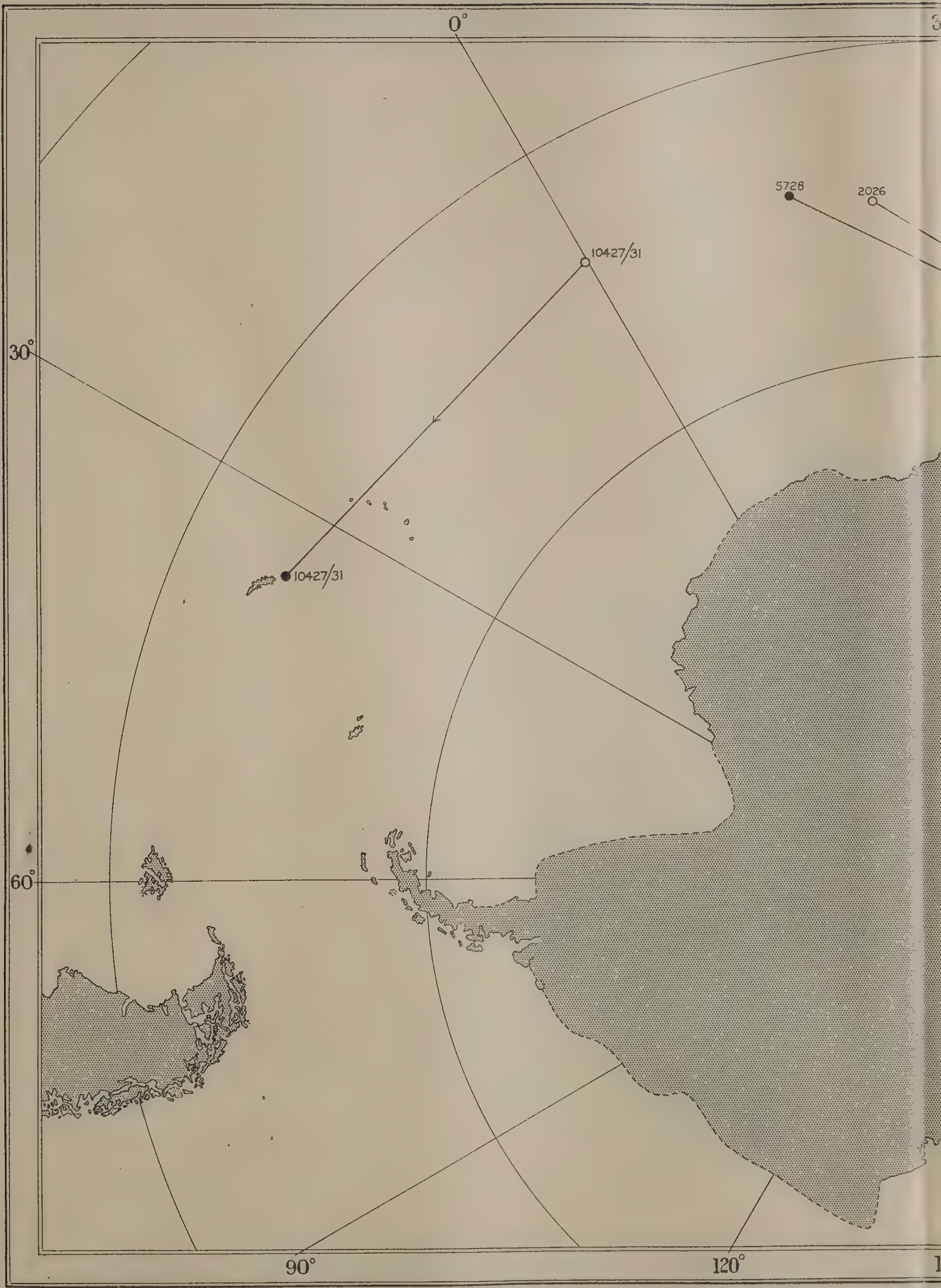
56°
3771
10427/31
903
10427/31
36°
34°
32° W

of marking and capture of 1-group whales.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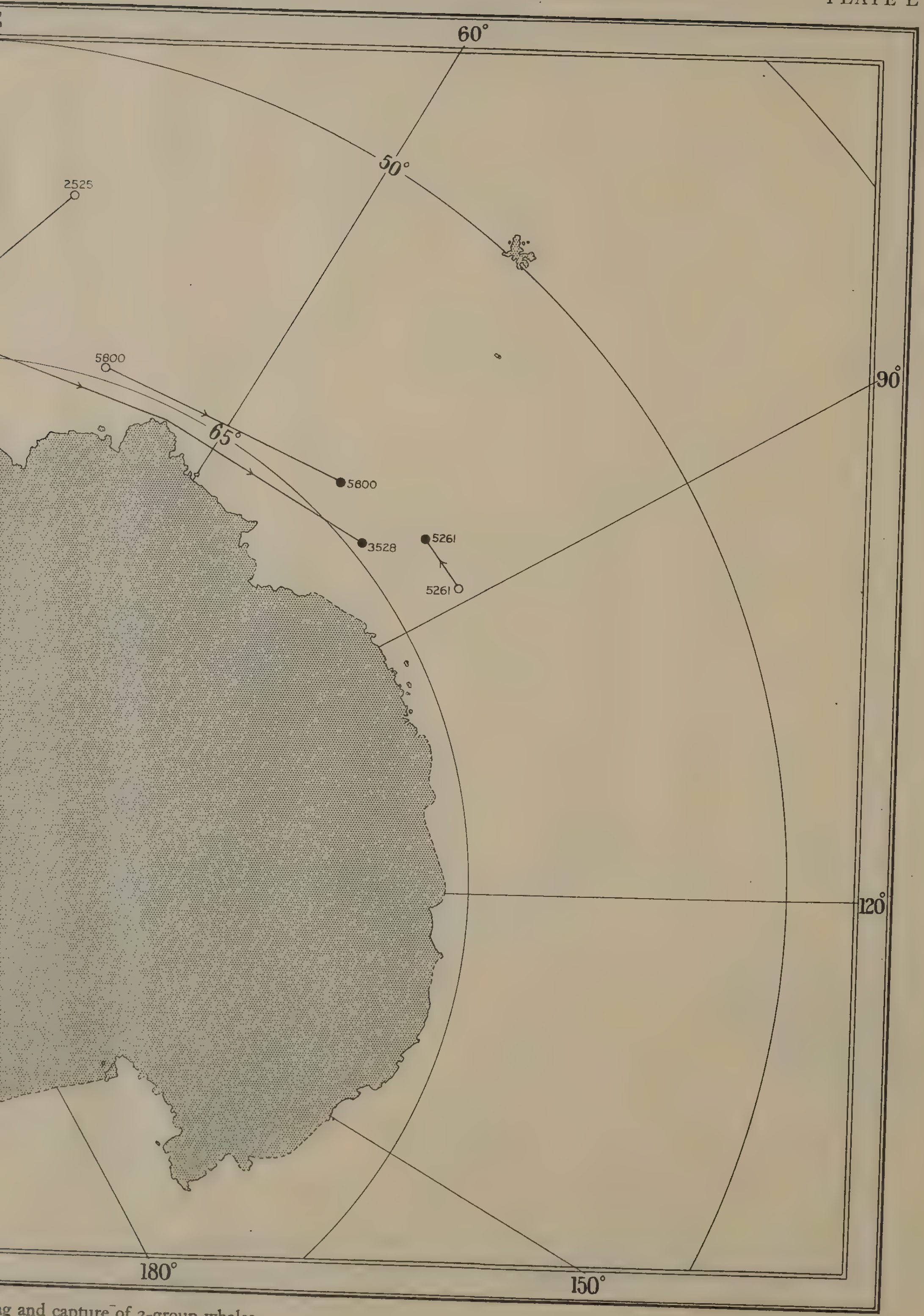
10427/31
10427/31
5728
2026

Blue whales. Southern Ocean. Positions

PLATE L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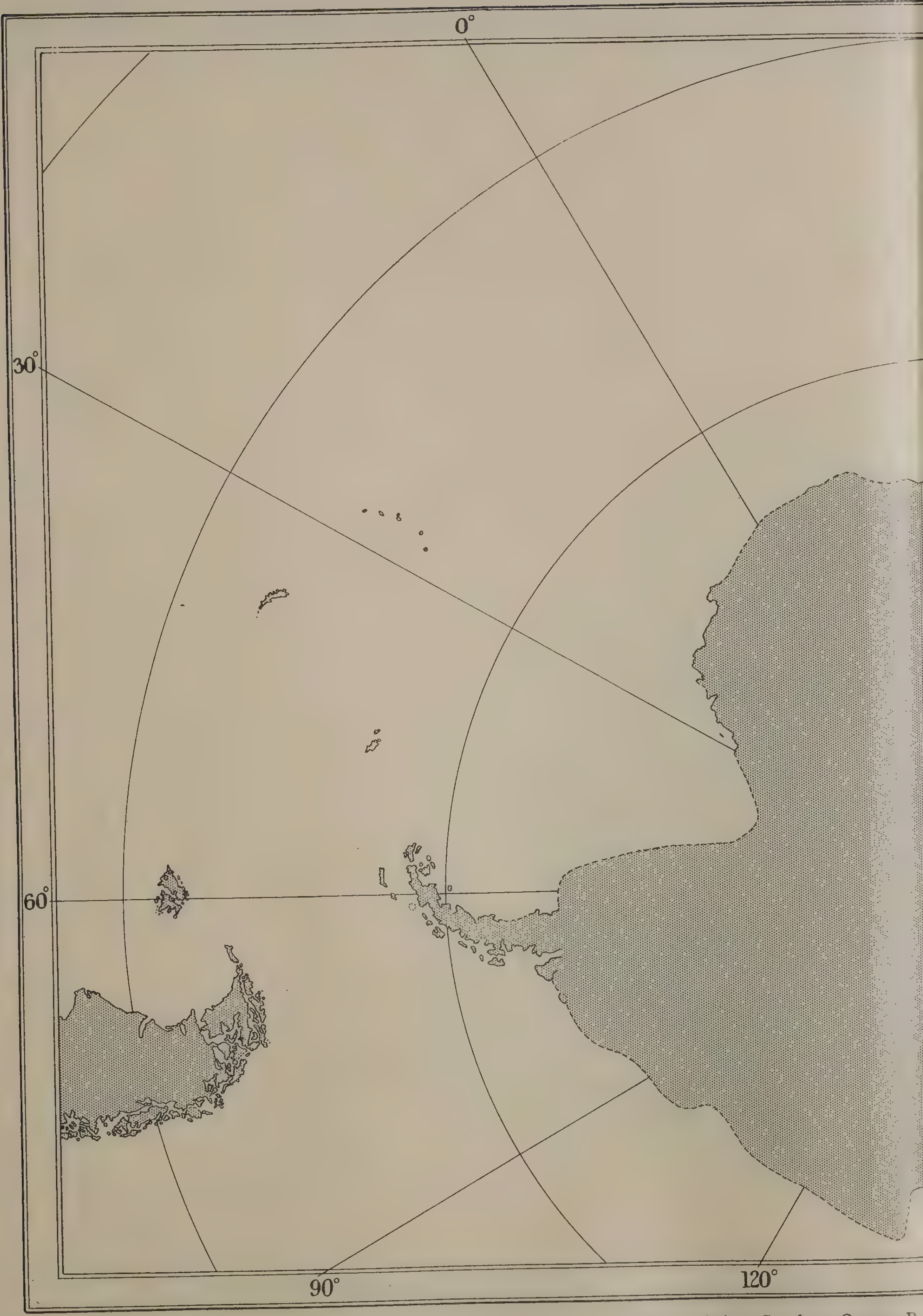
65°
5800
5261
3528
5261
90°
120°
180°
150°

g and capture of 2-group whales.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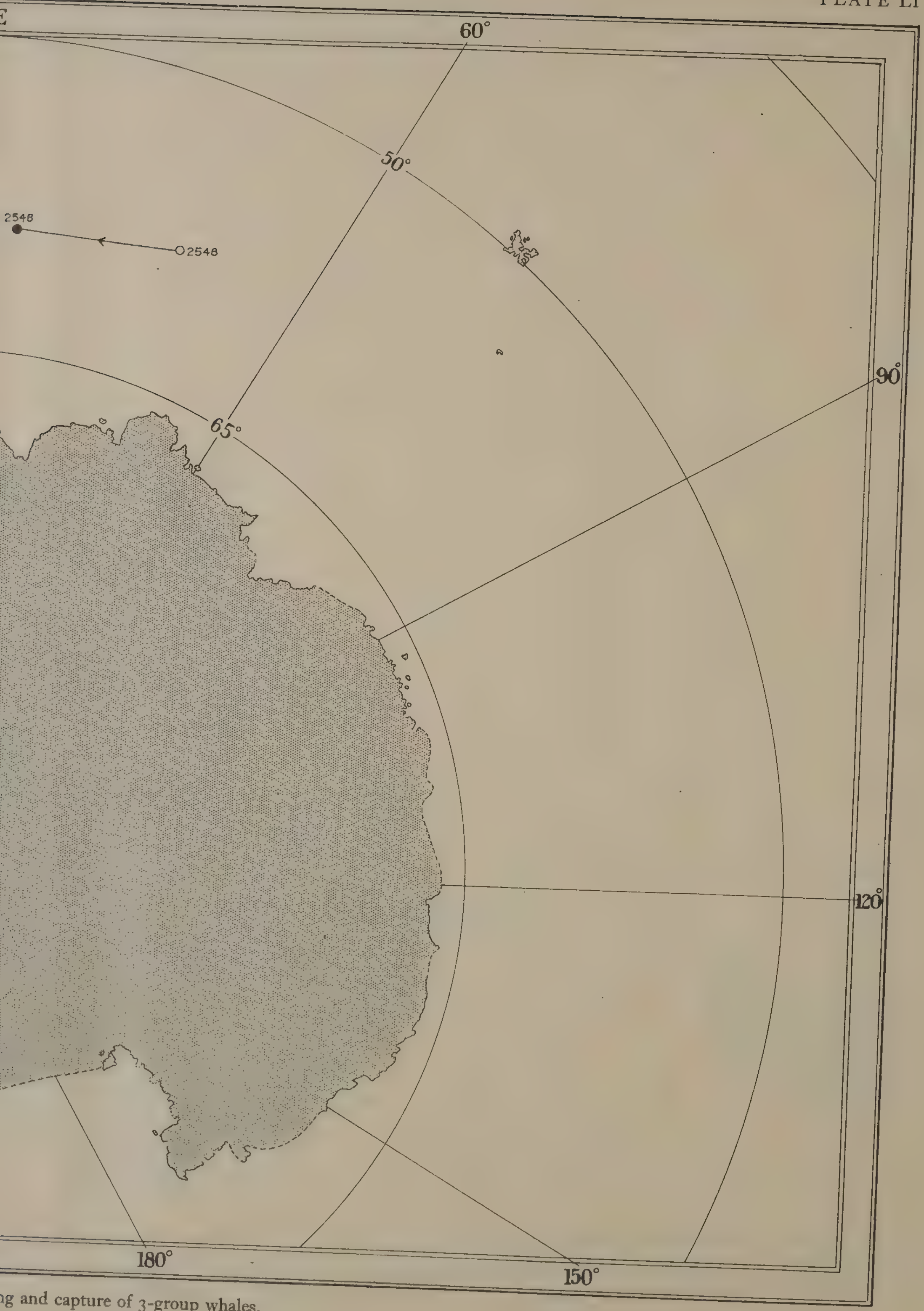
Blue whales. Southern Ocean. Po

PLATE LI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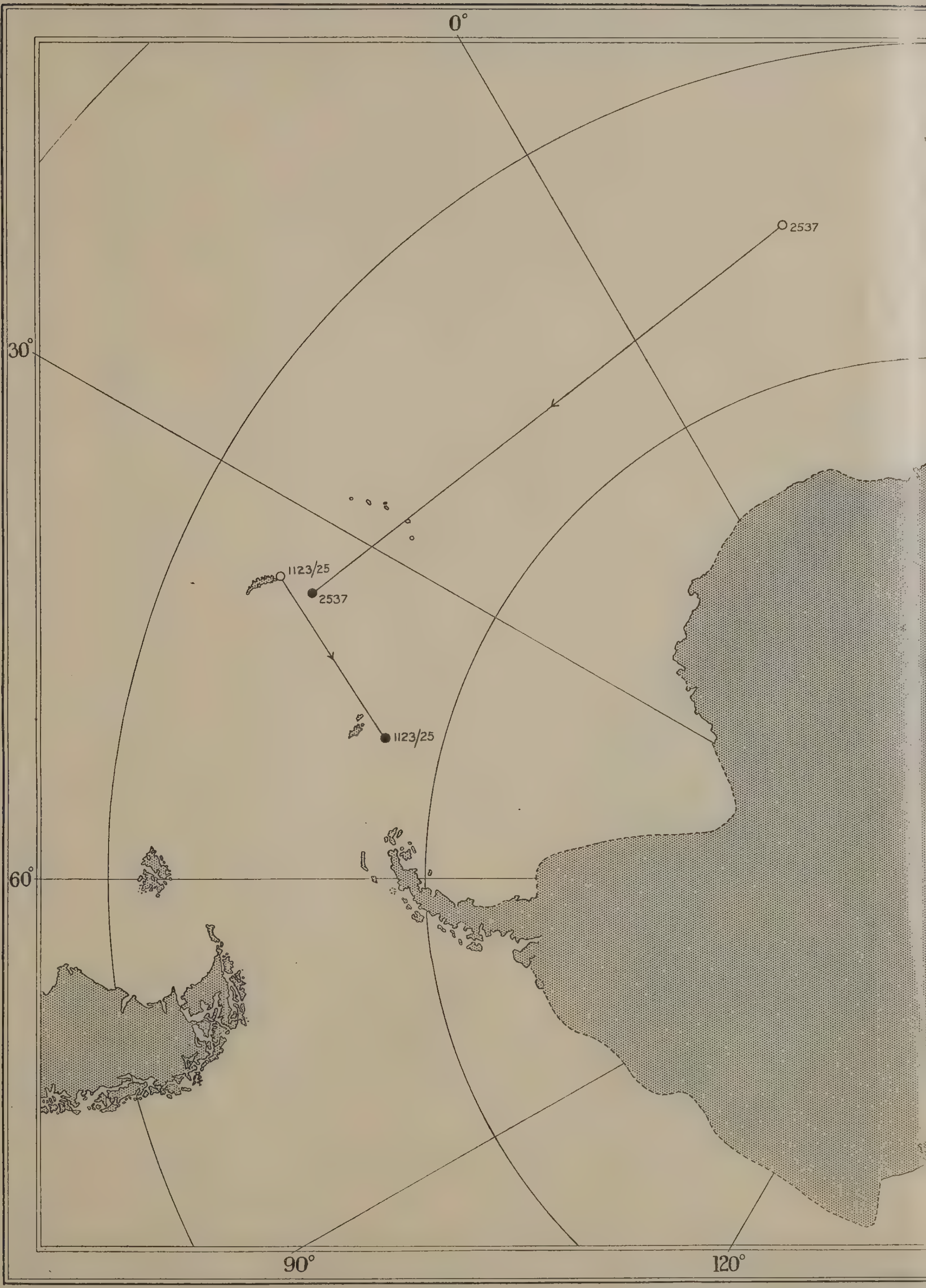
ng and capture of 3-group whales.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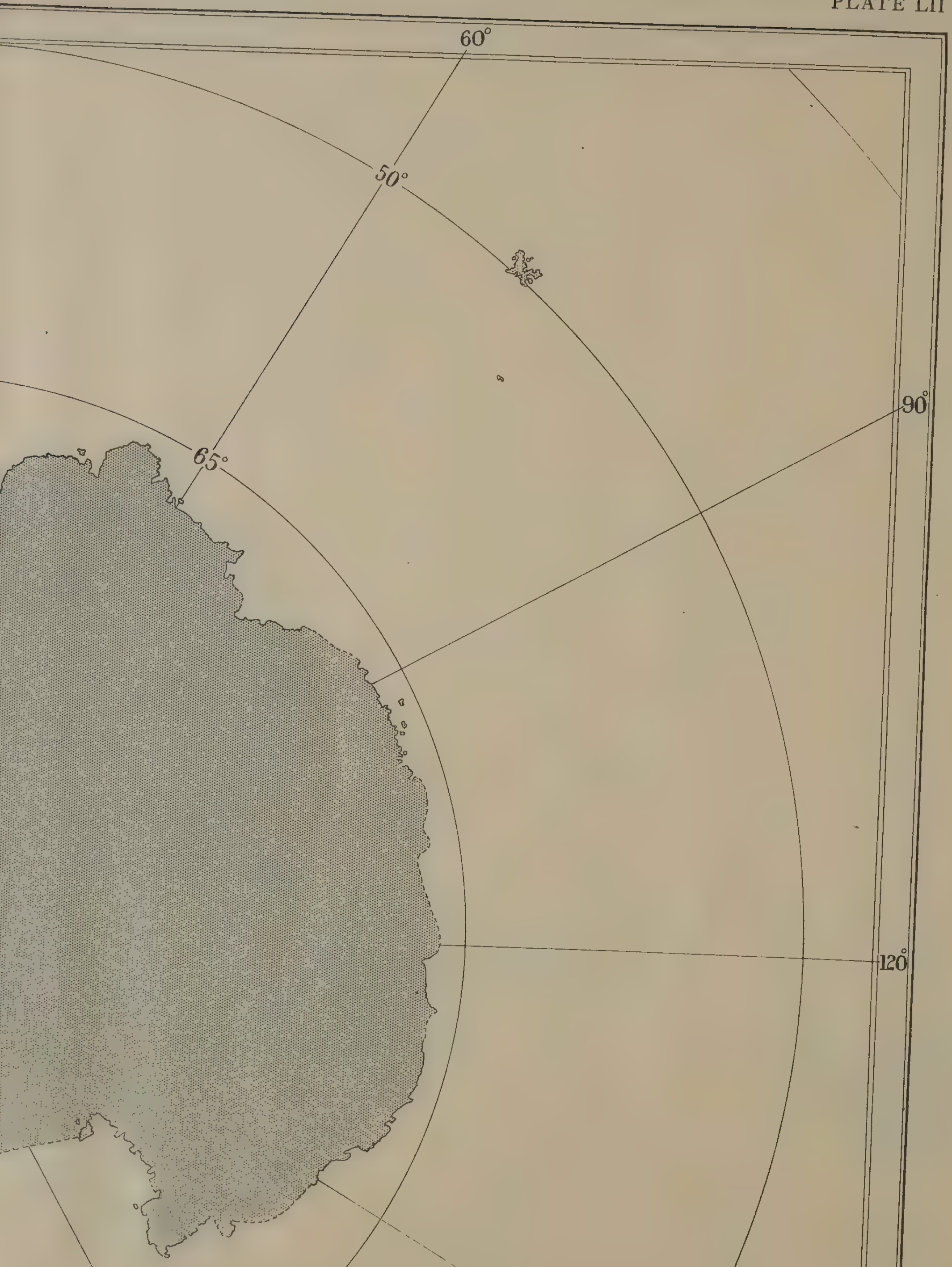
1123/25
2537
1123/25

Blue whales. Southern Ocean. Positio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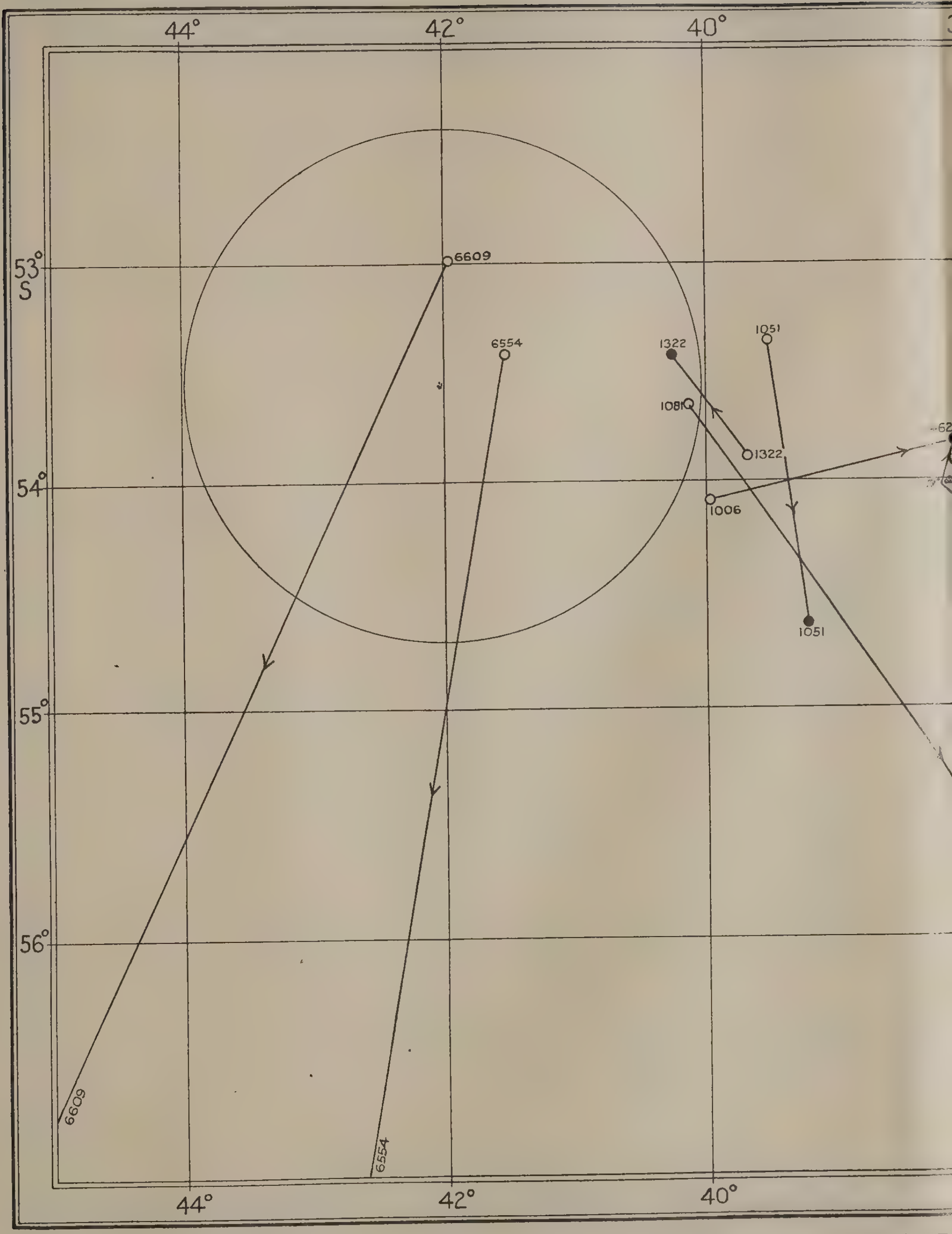
nd capture of 4-group whales.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53° S
54°
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56°
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1081
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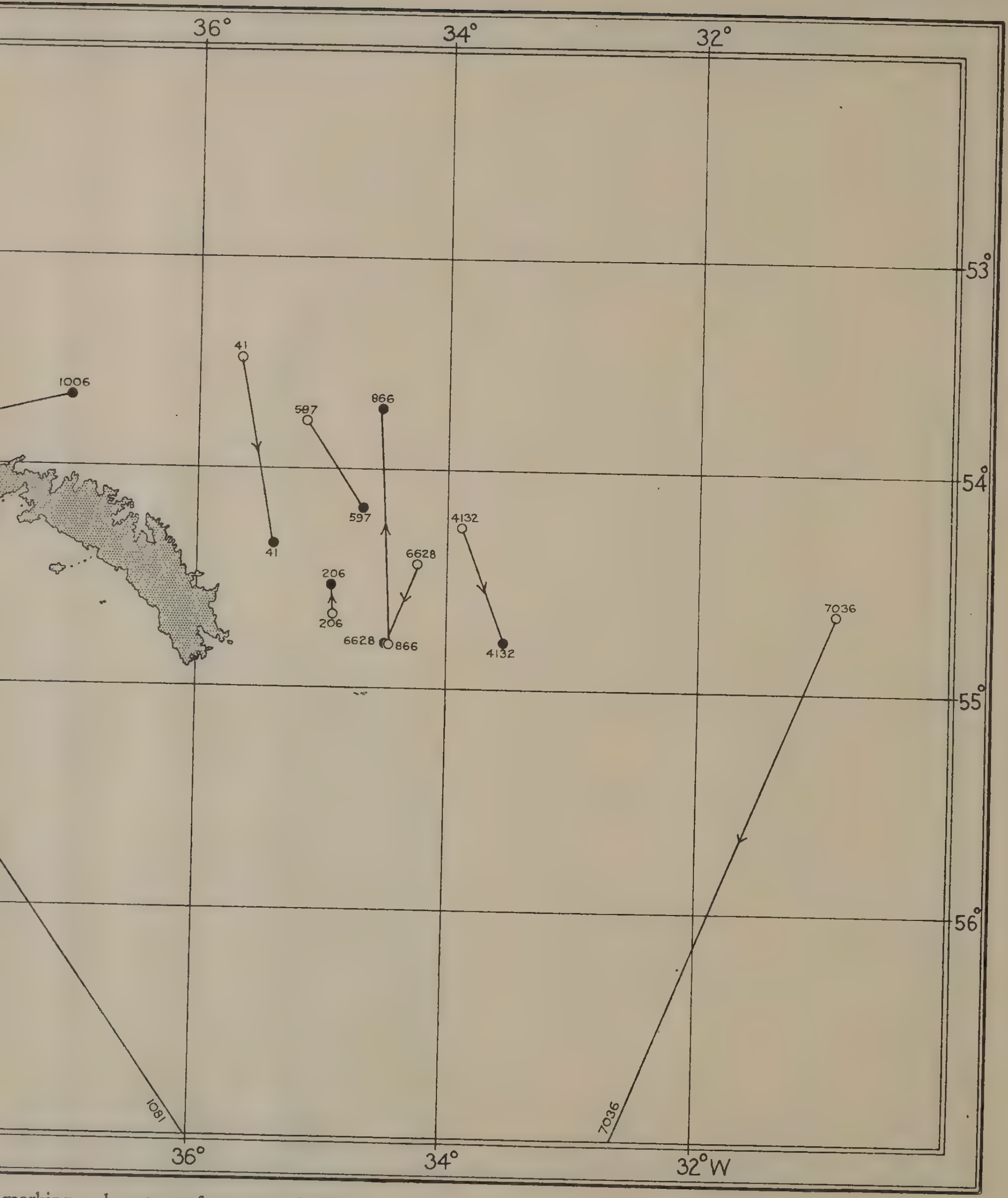
6609
6554
44°
42°
40°

Fin whales. South Georgia. P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587
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36°
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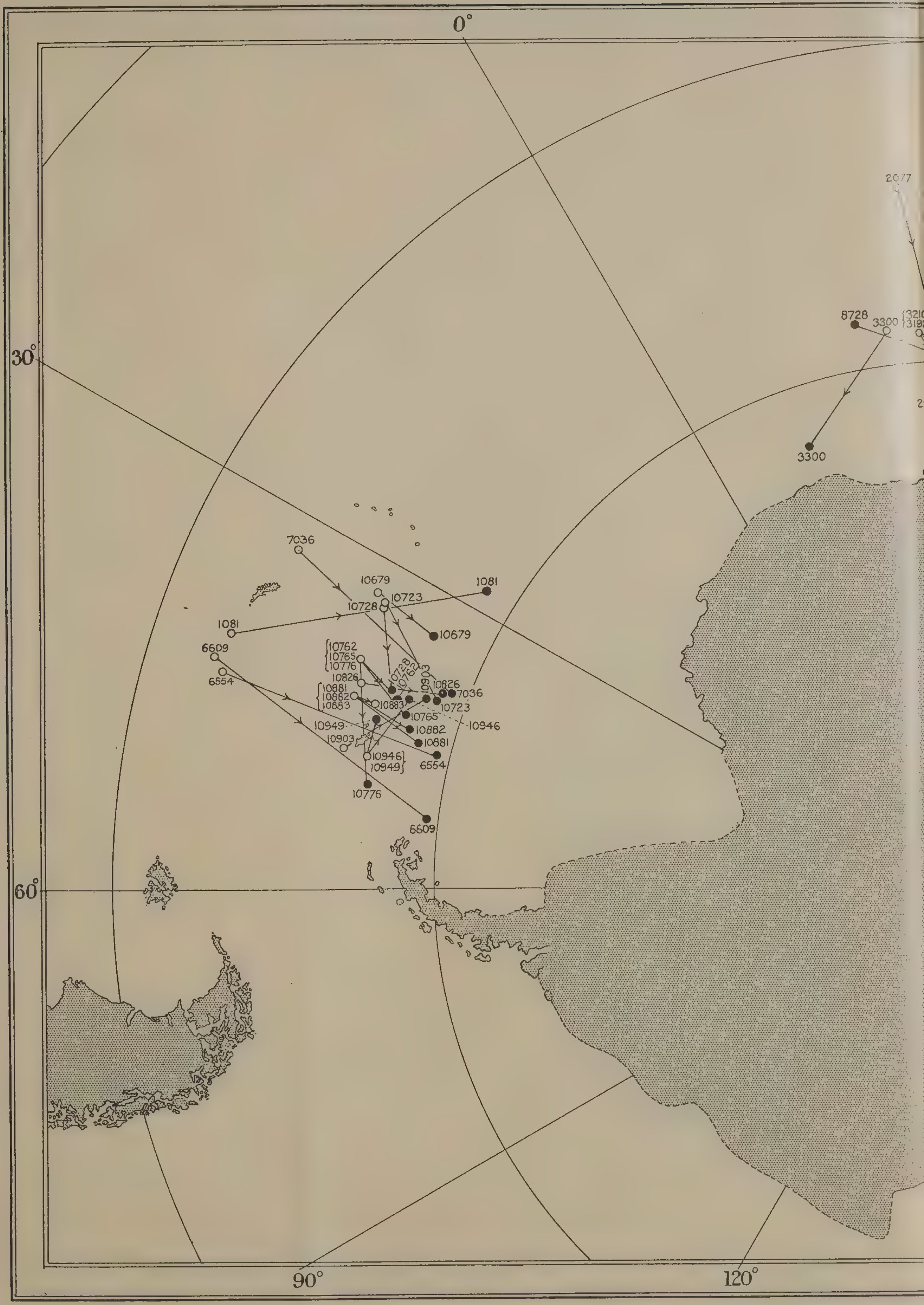
marking and capture of o-group whales.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10728
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10883
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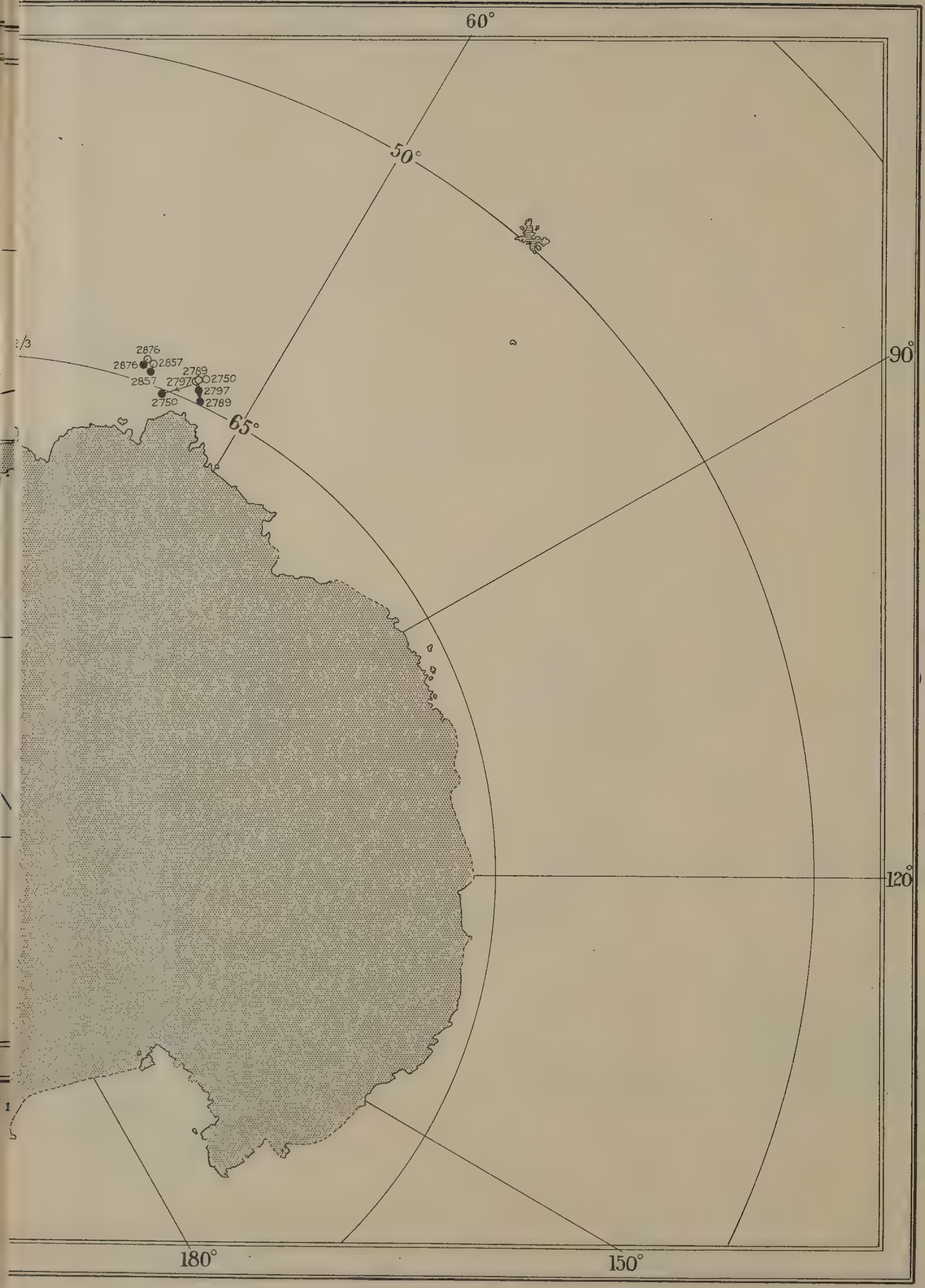
Fin whales. Southern Ocean. Positi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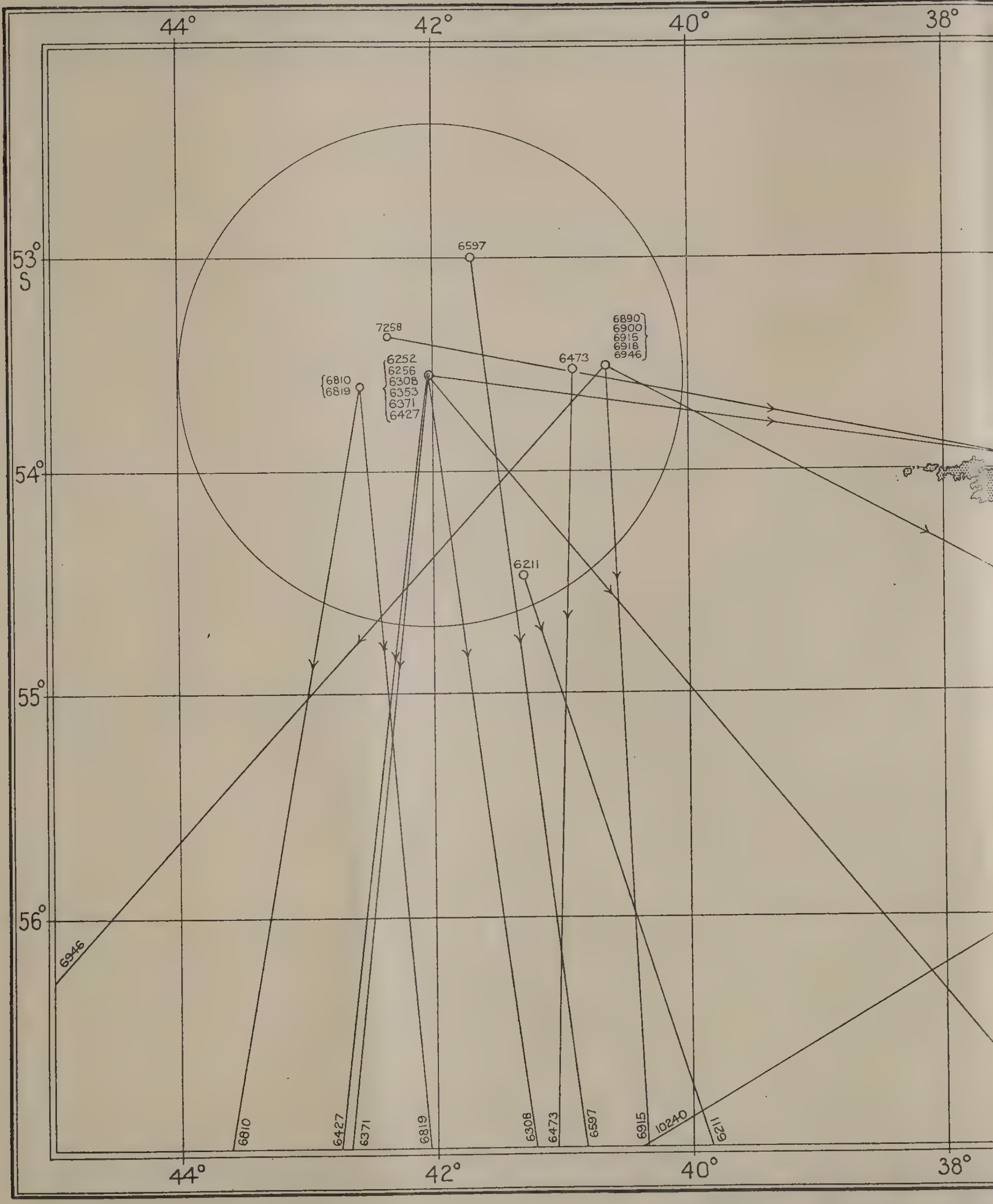
/3

arking and capture of o-group whales.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56°
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6473
6252
6256
6308
6353
6371
6427
6810
6819
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6371
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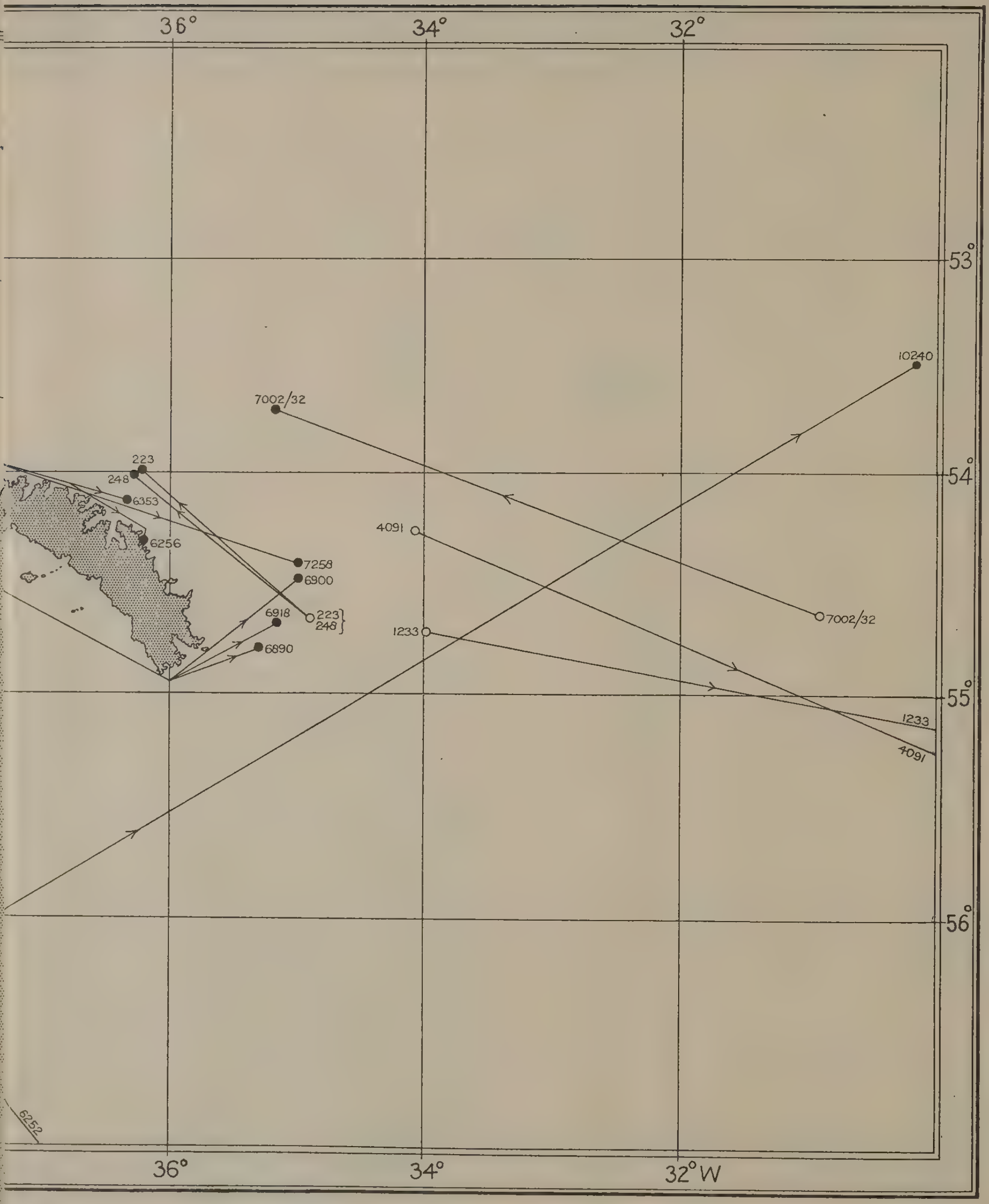
6308
6473
6597
6915
10240
6211

Fin whales. South Georgia. Positions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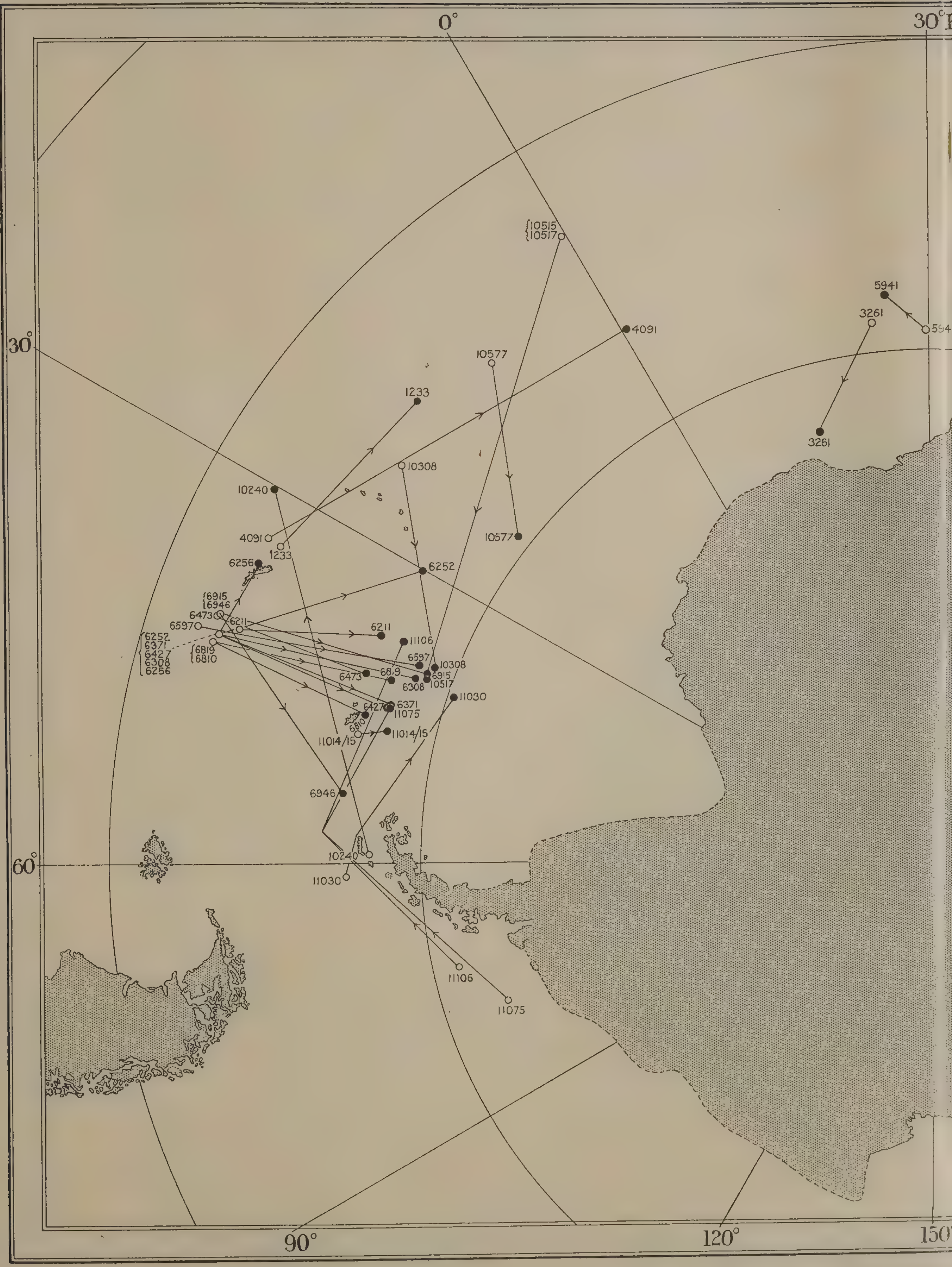
34°
32°
36°
34°
32°W
53°
54°
55°
56°
10240
7002/32
223
248
6353
6256
7258
6900
6918
223
248
6890
4091
1233
7002/32
1233
4091
6252

arking and capture of 1-group whales.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6252
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6211
11106
6597
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6473
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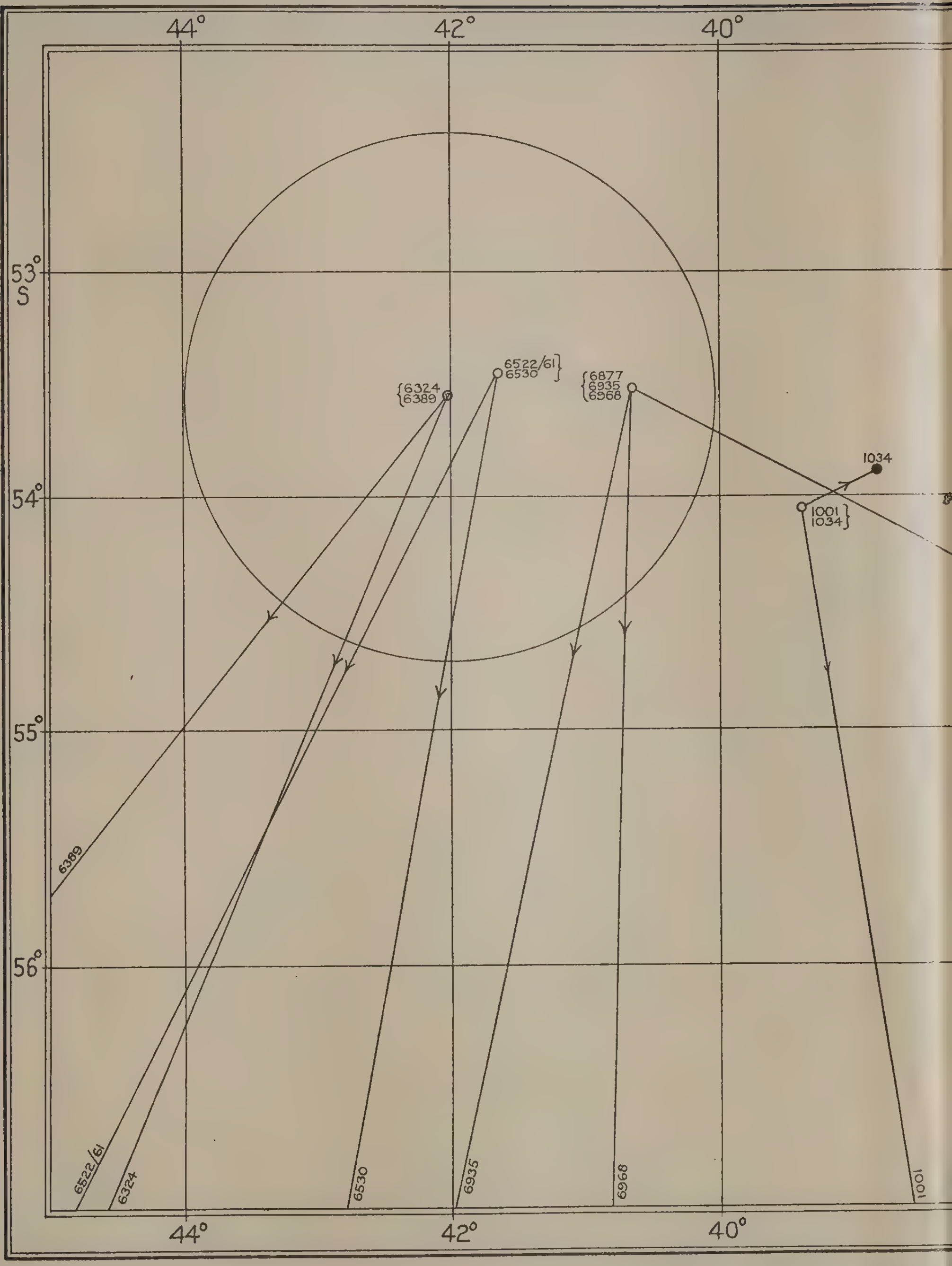
Fin whales. Southern Ocean. Positions of

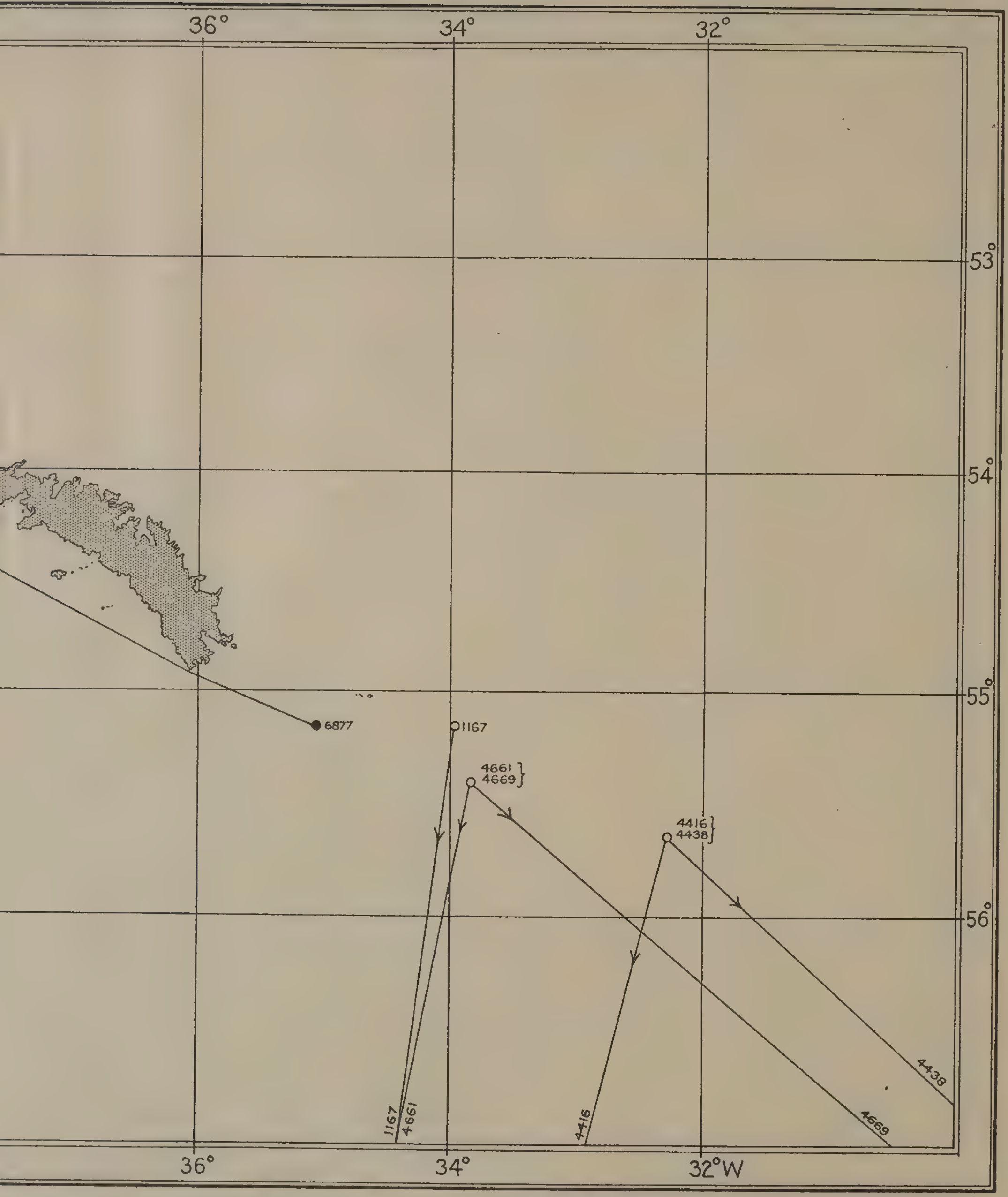
60°
50°
65°
90°
120°
150°
180°
2982
2982

and capture of 1-group whales.


44°
42°
40°
53° S
54°
55°
56°
6522/61
6530
6324
6389
6877
6935
6968
1034
1001
1034
6389
6522/61
6324
6530
6935
6968
1001
44°
42°
40°

Fin whales. South Georgia.

PLATE LVII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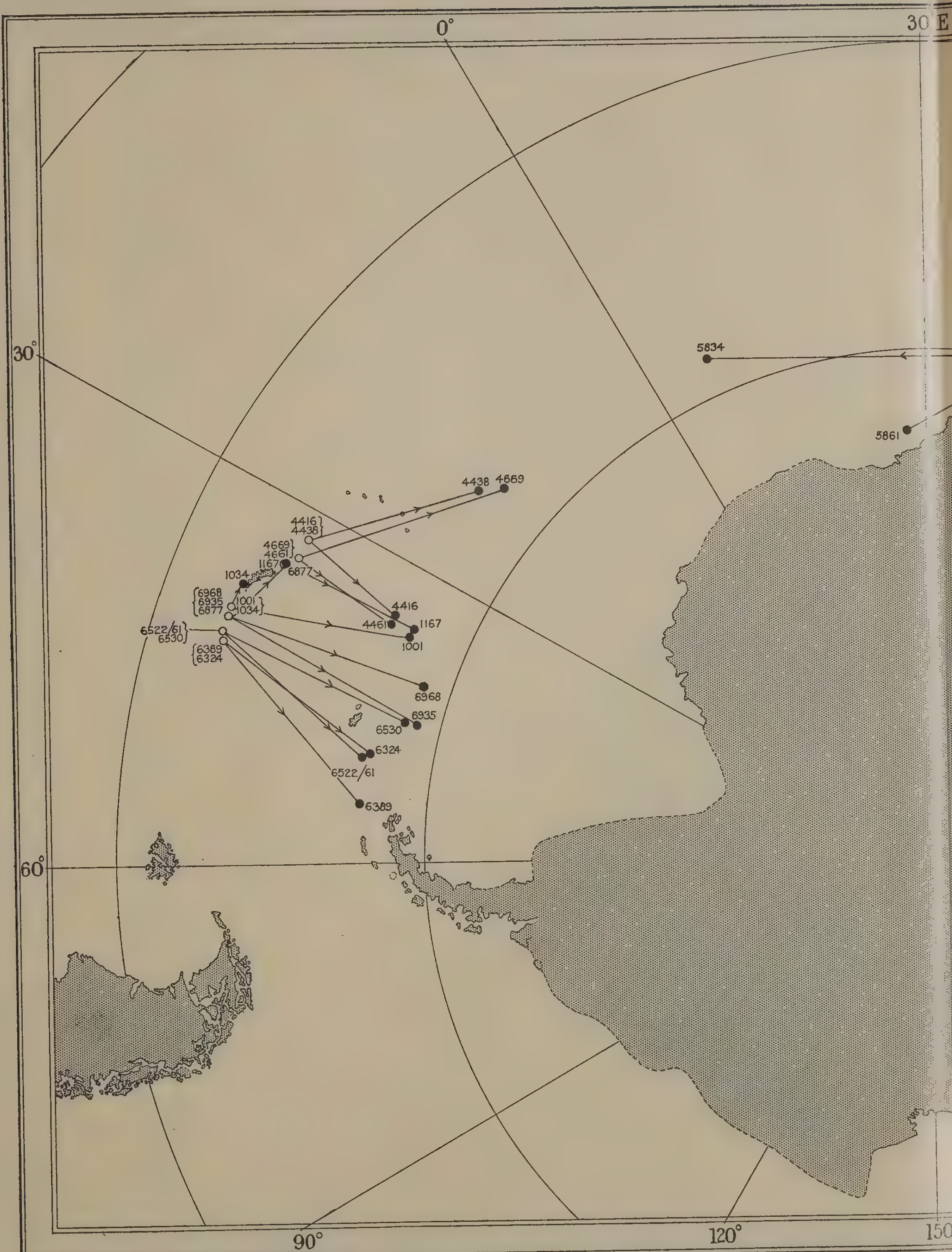
34°
32°
53°
54°
55°
56°
6877
1167
4661
4669
4416
4438
1167
4661
4416
4669
4438
36°
34°
32°W

f marking and capture of 2-group whales.


0°
30 E
30°
60°
90°
120°
150
5834
5861
4438
4669
4416
4438
4669
4661
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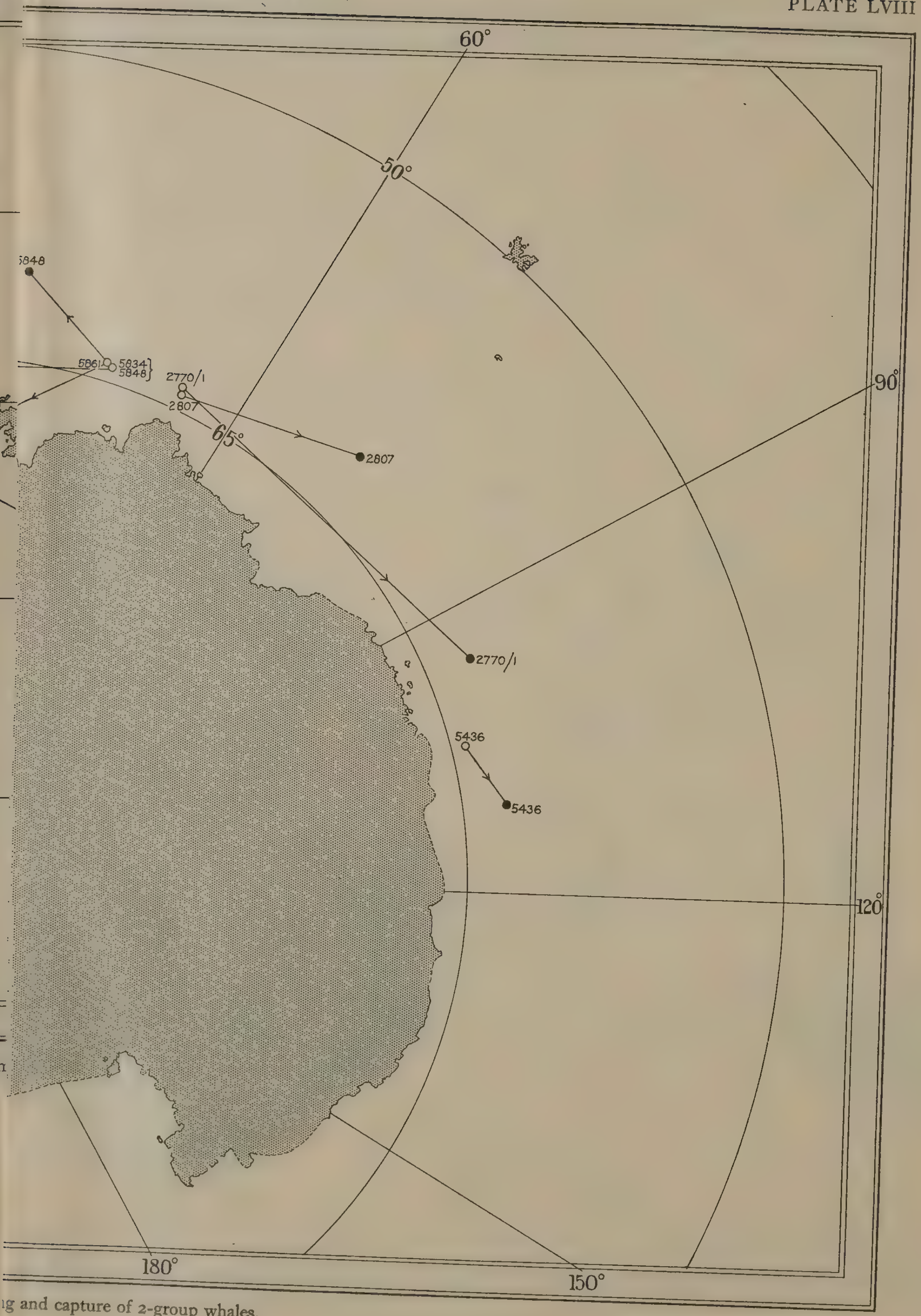
6877
1034
6968
6935
6877
1001
1034
6522/61
6530
6389
6324
4416
4461
1167
1001
6968
6935
6530
6324
6522/61
6389

Fin whales. Southern Ocean. Positions of


60°
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65°
90°
120°
180°
150°
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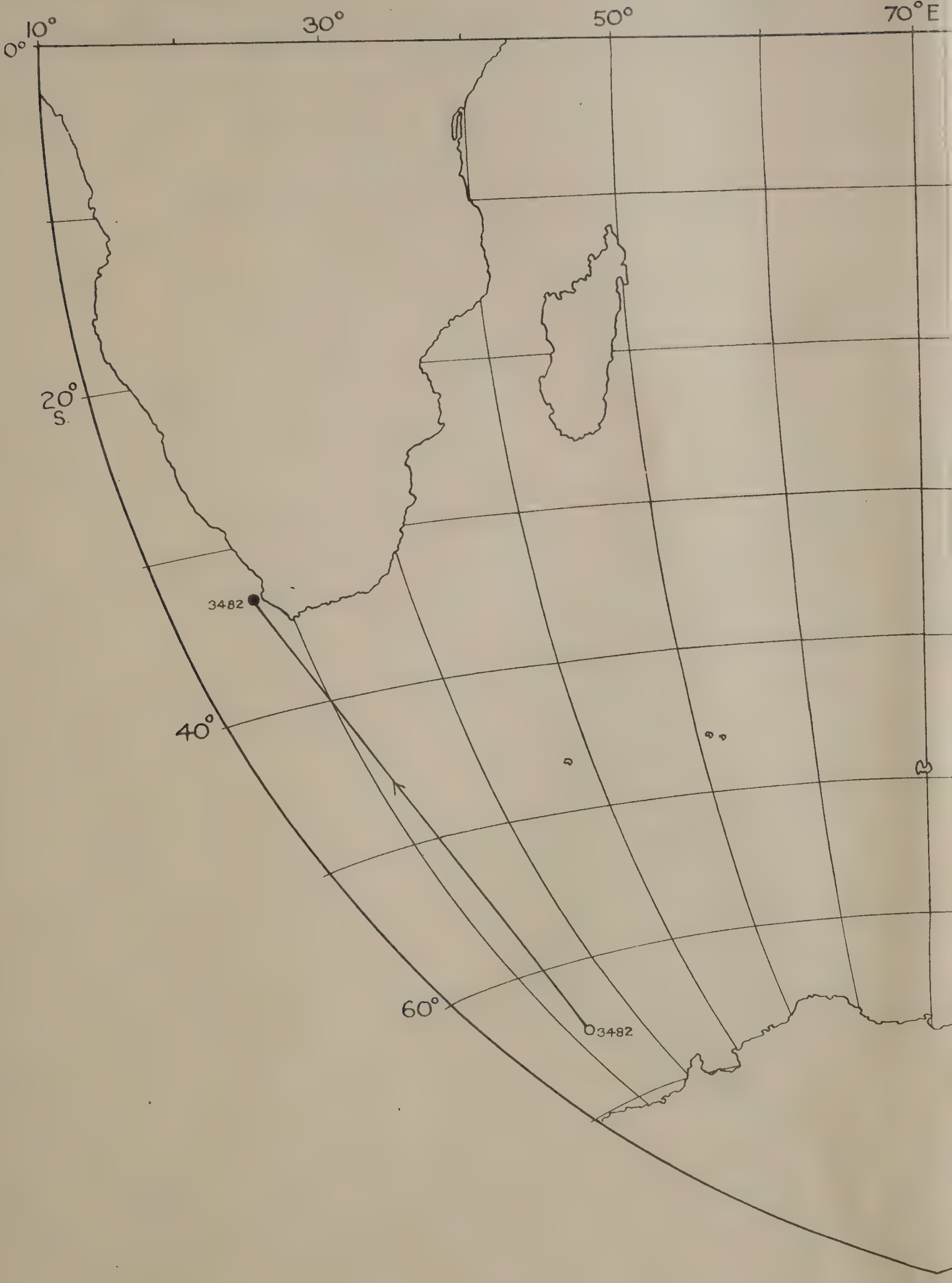
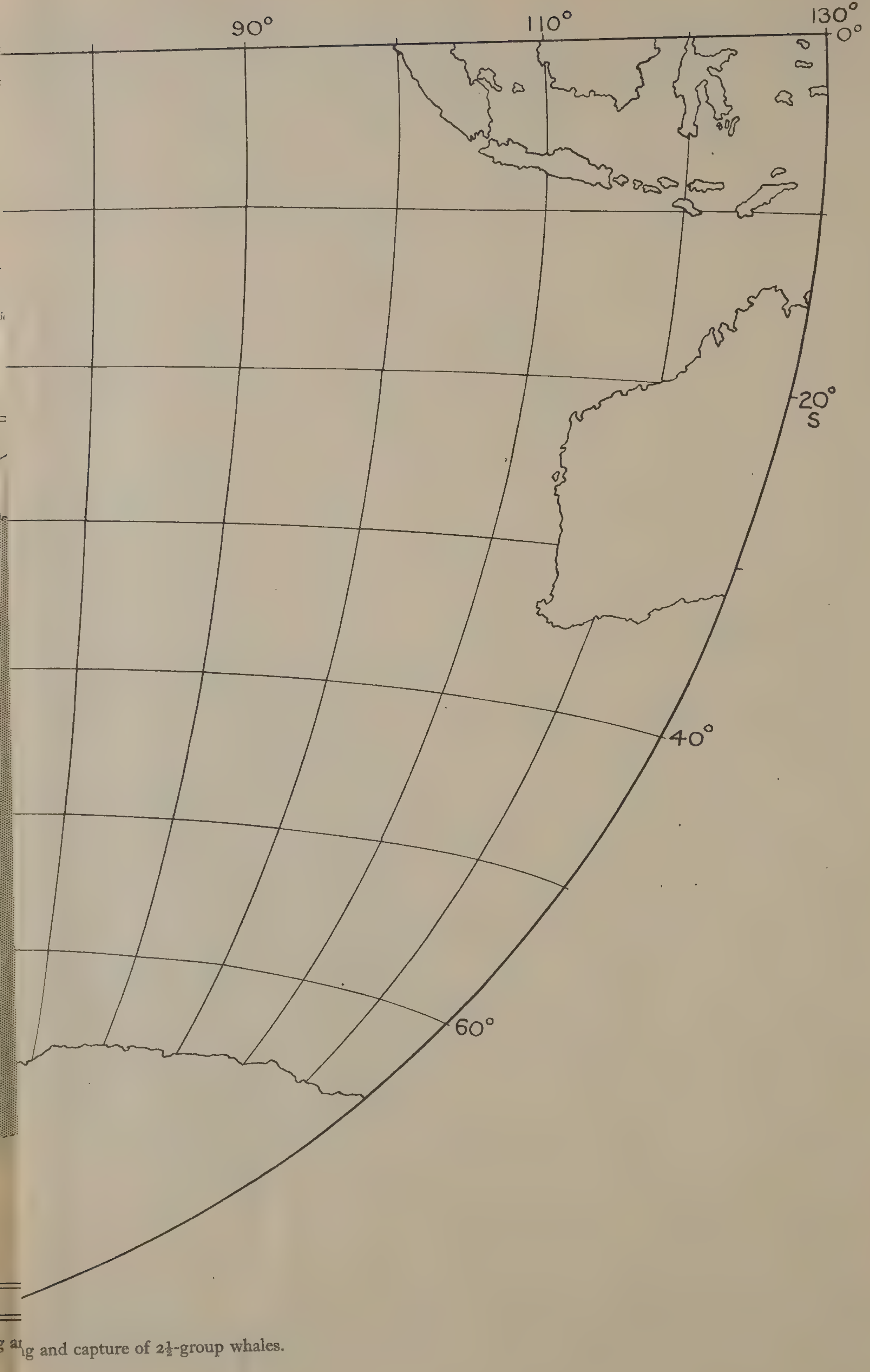
5861
5834
5848
2770/1
2807
2807
2770/1
5436
5436

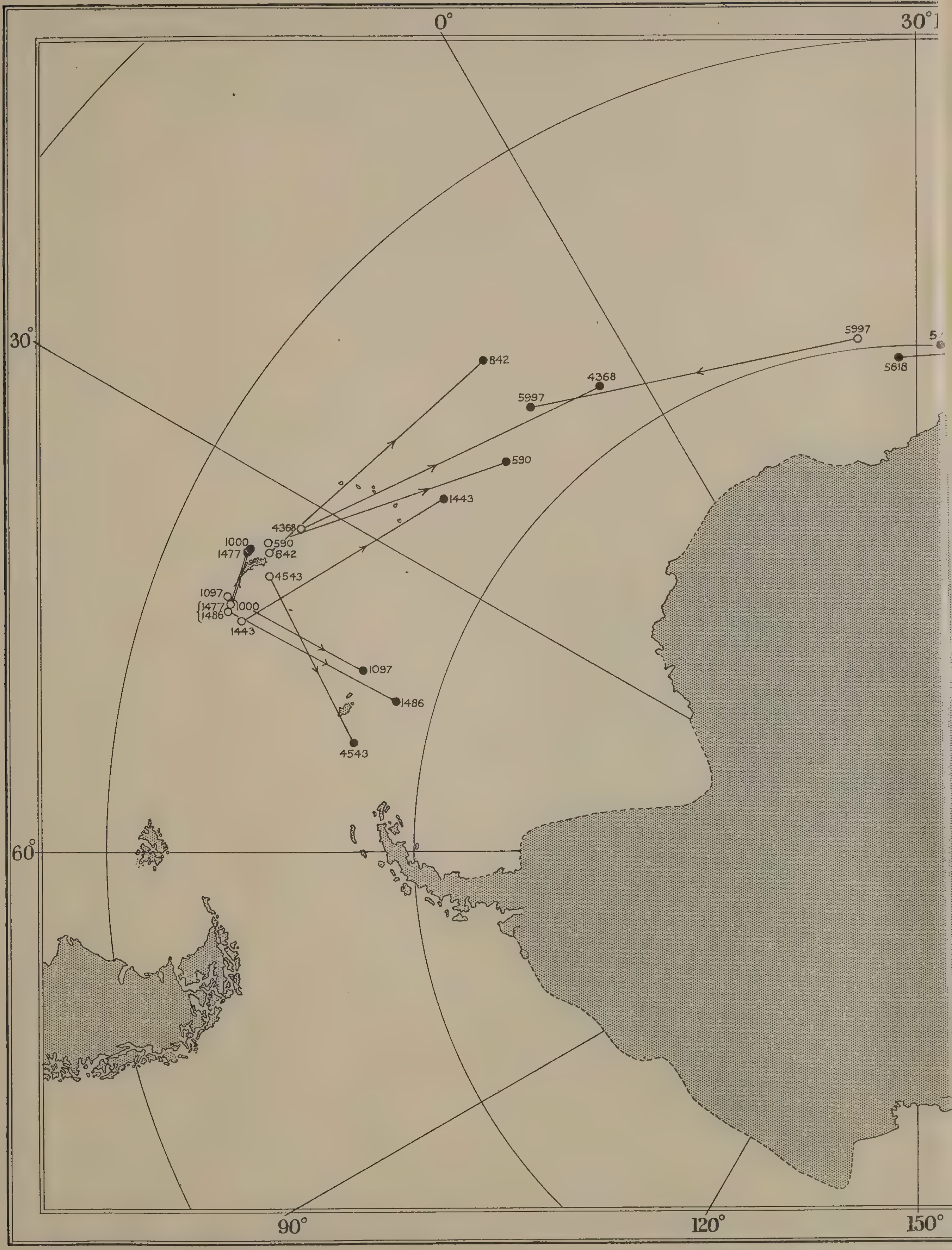
g and capture of 2-group whales.


10°
30°
50°
70° E
0°
20° S.
40°
60°
3482
3482

Fin whales. Indian Ocean. Positions of m


90°
110°
130°
0°
20° S
40°
60°

g and capture of 2½-group whales.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60°
90°
120°
150°
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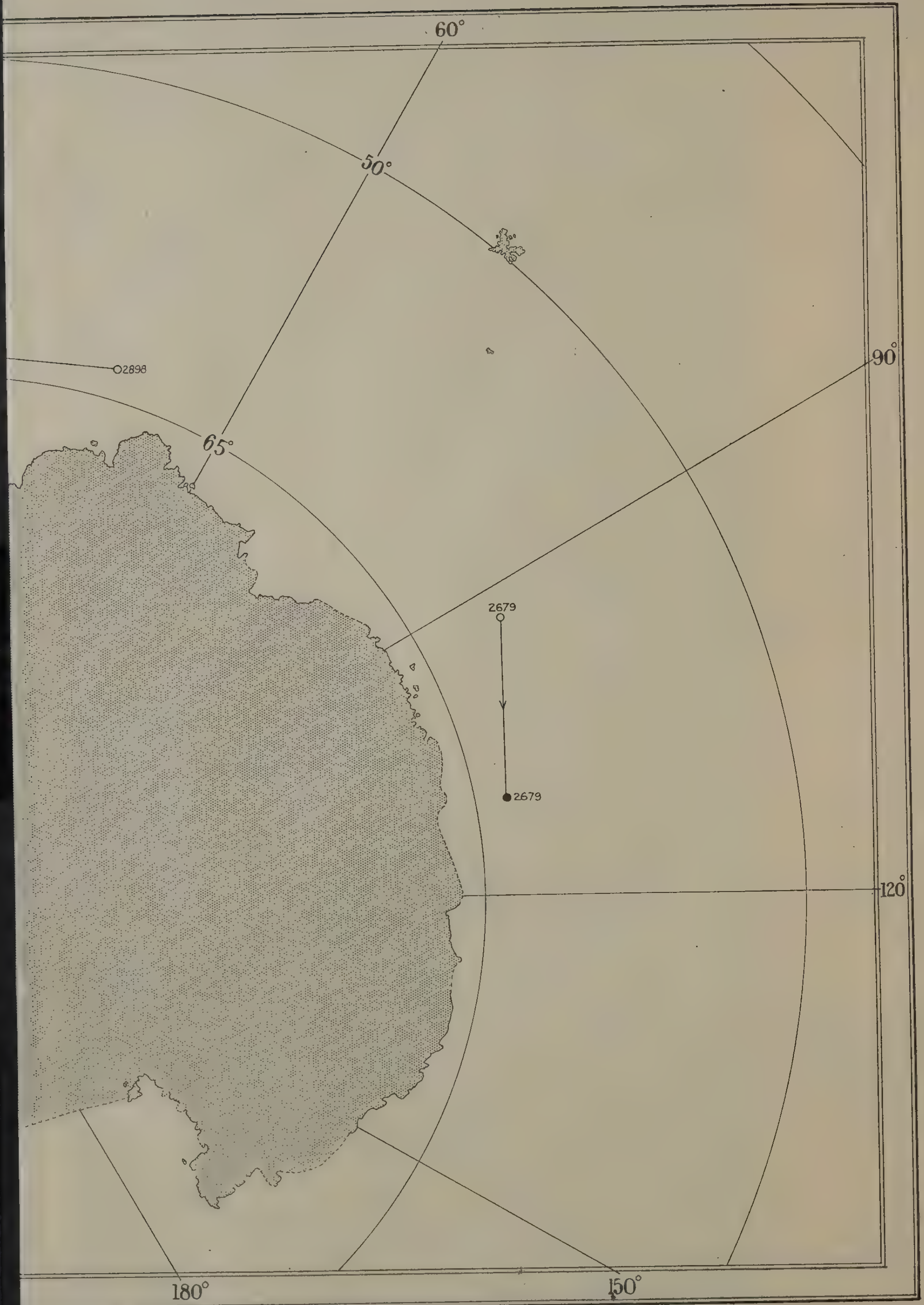
5818
842
4368
5997
590
1443
4368
1000
590
1477
842
4543
1097
1477
1000
1486
1443
1097
1486
4543

Fin whales. Southern Ocean. Positions of m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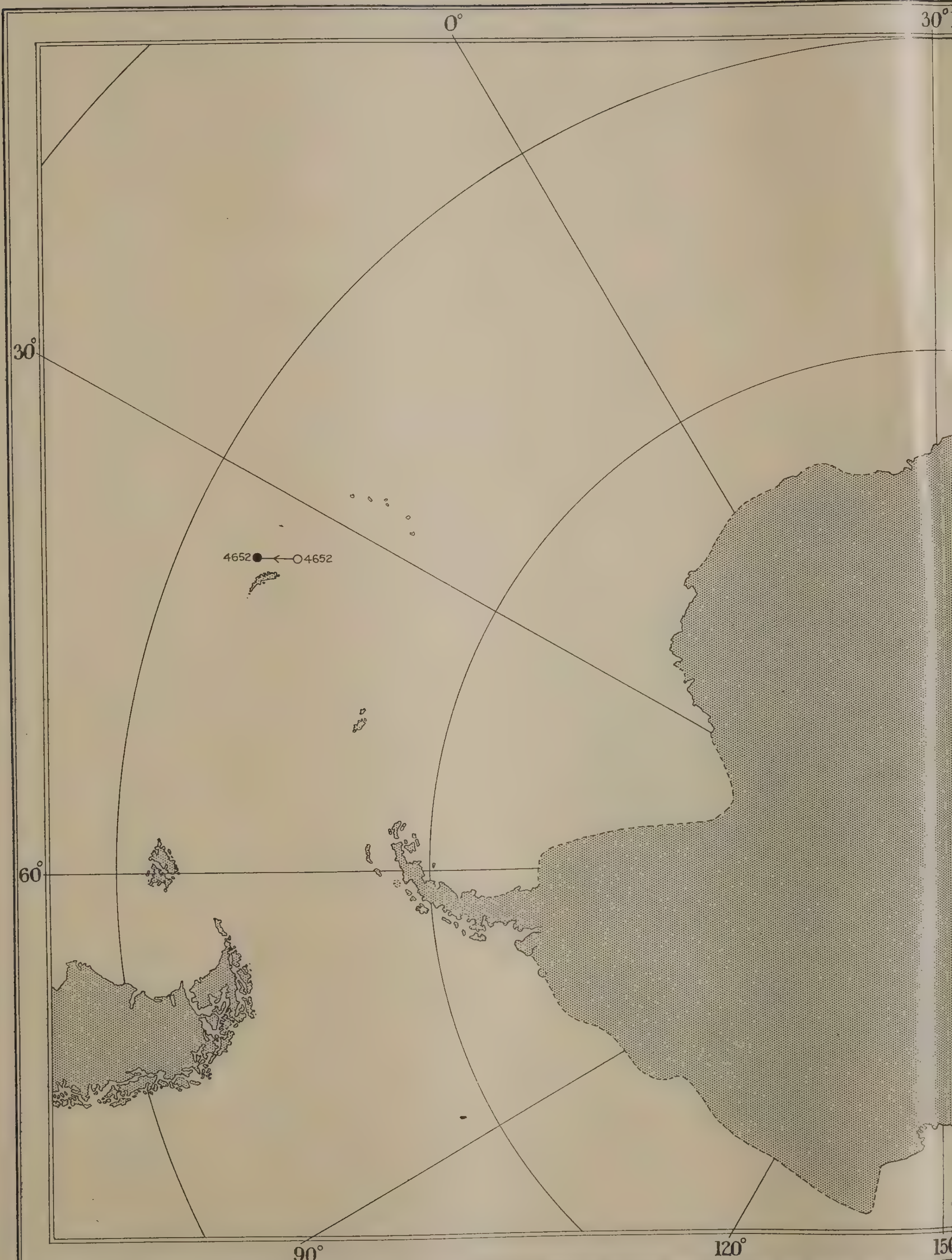
50°
65°
90°
120°
150°
180°
2898
2679
2679

ing and capture of 4-group whales.


0°
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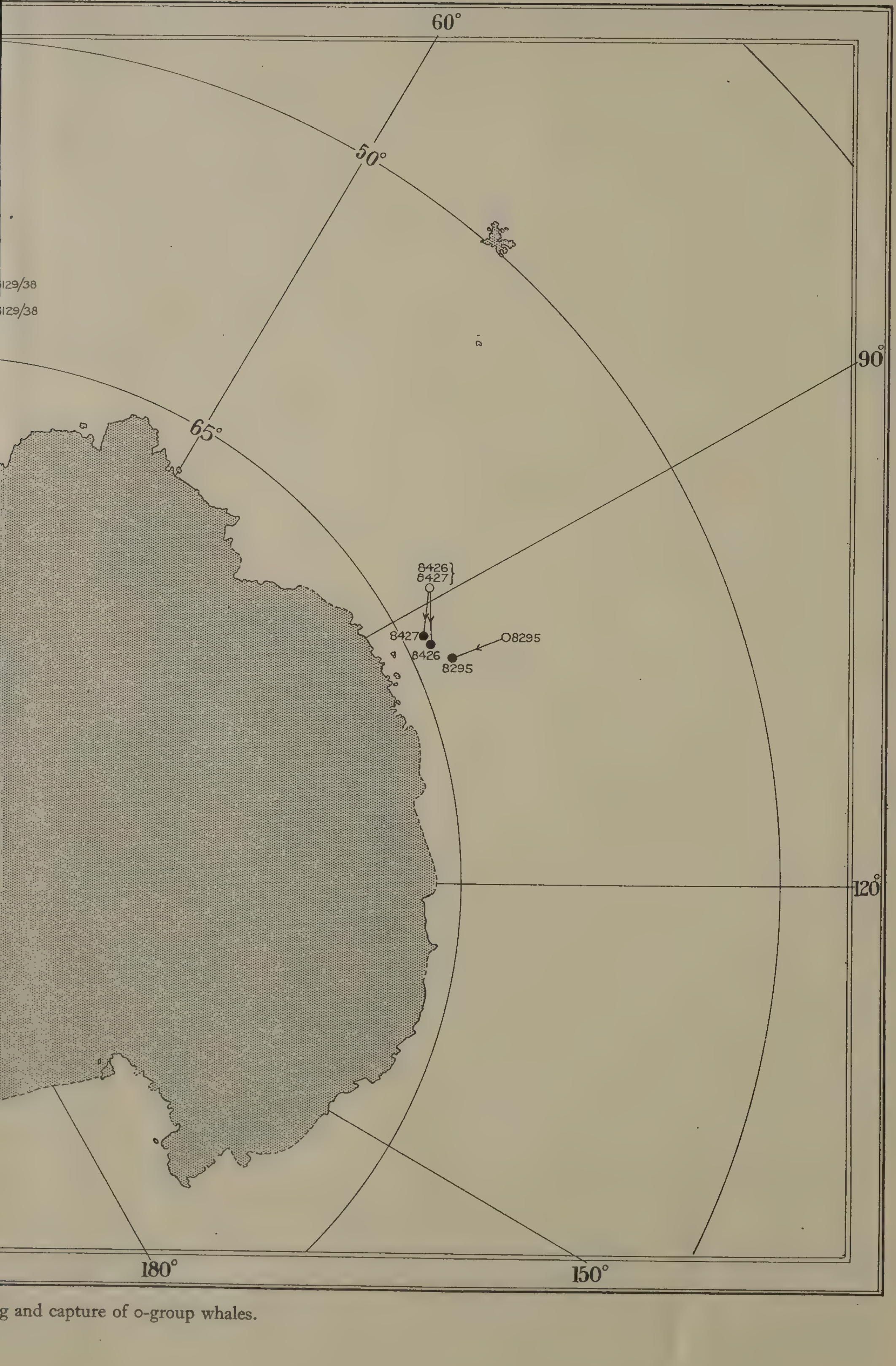
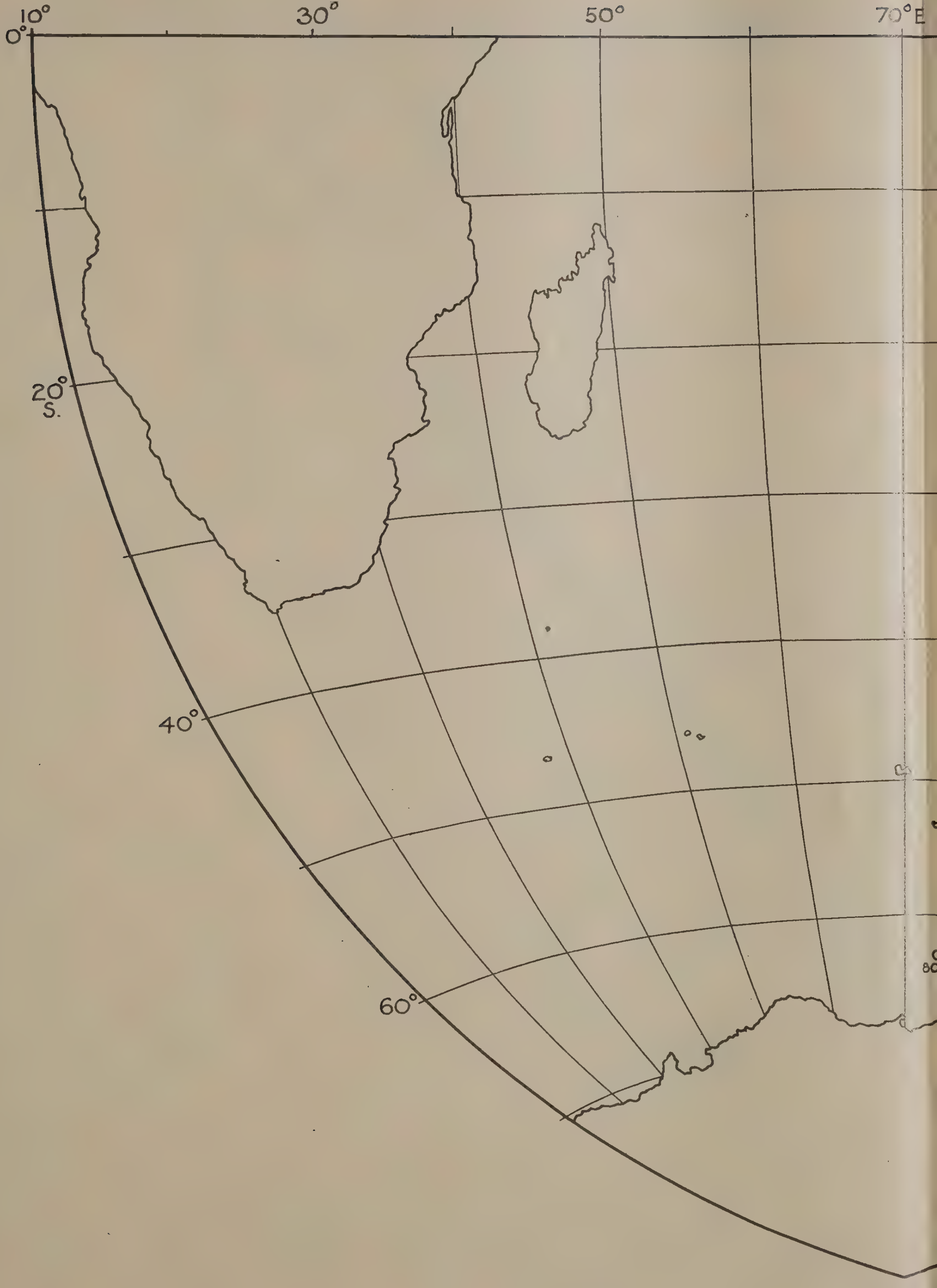
30°
60°
90°
120°
4652
4652

Humpback whales. Southern Ocean. Positions of

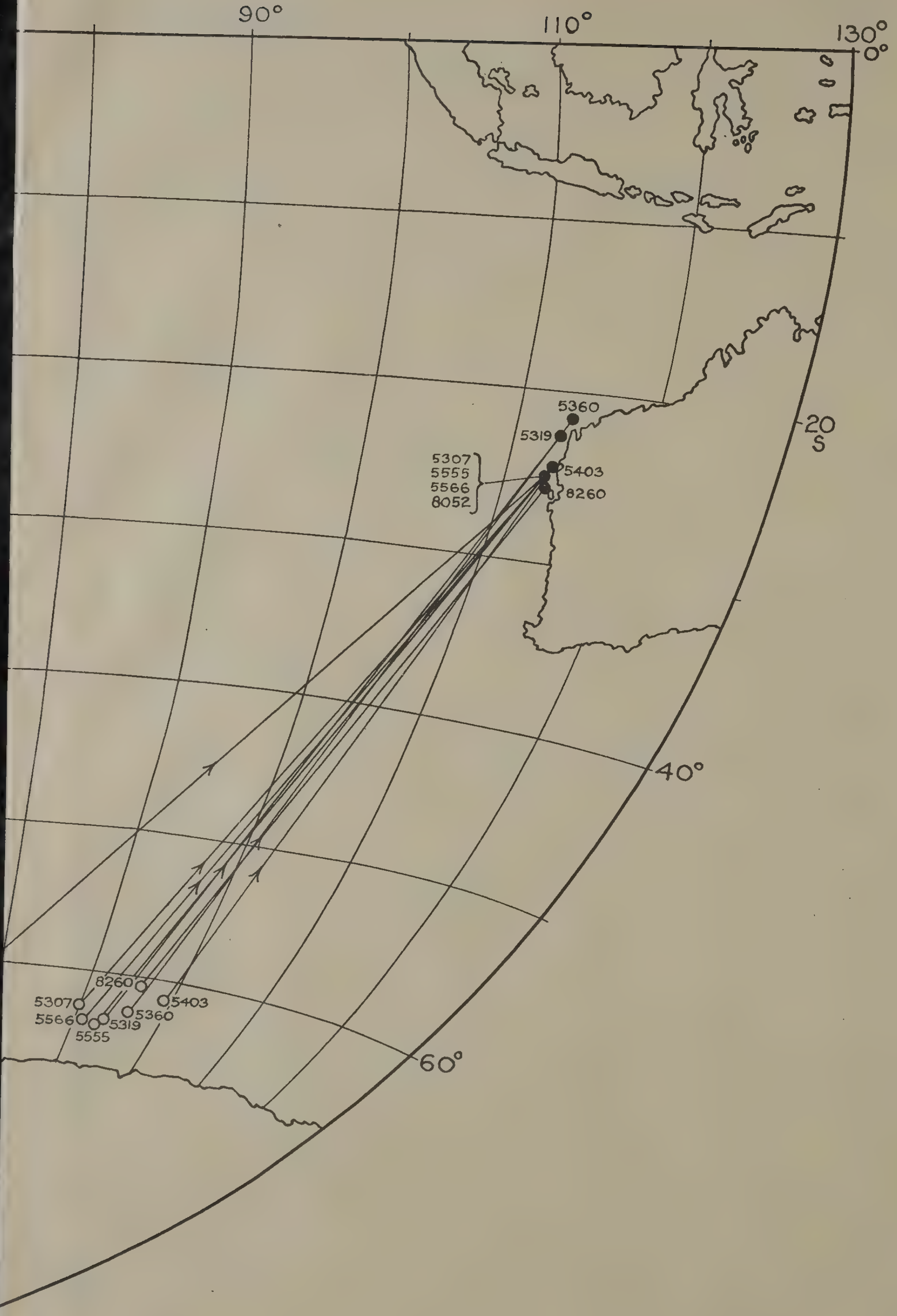

60°
50°
65°
90°
120°
150°
180°
129/38
129/38
8426
8427
8427
8426
8295
8295

g and capture of o-group whales.

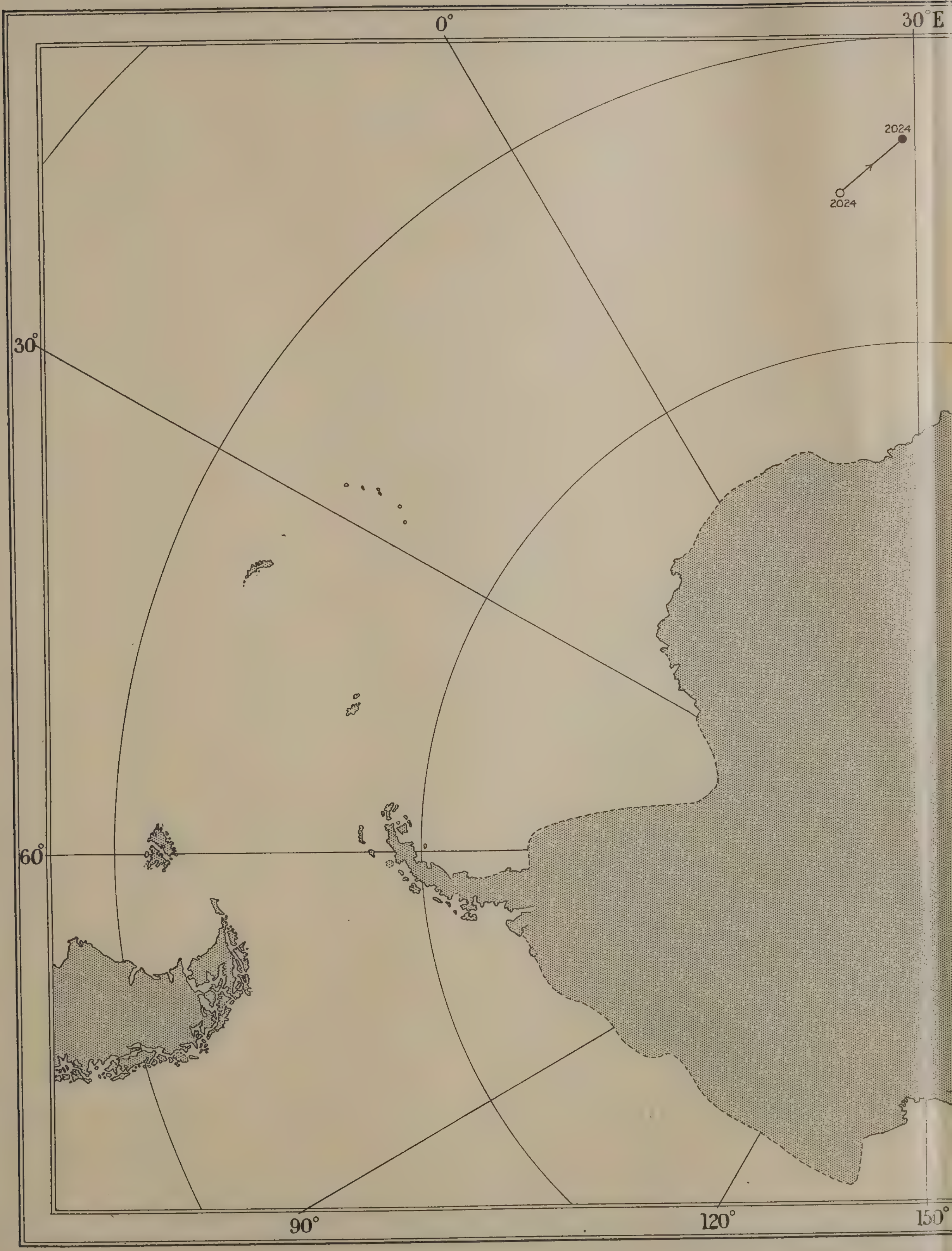

10°
30°
50°
70°E
0°
20° S.
40°
60°

Humpback whales. Indian Ocean. Positions of

PLATE LXIII

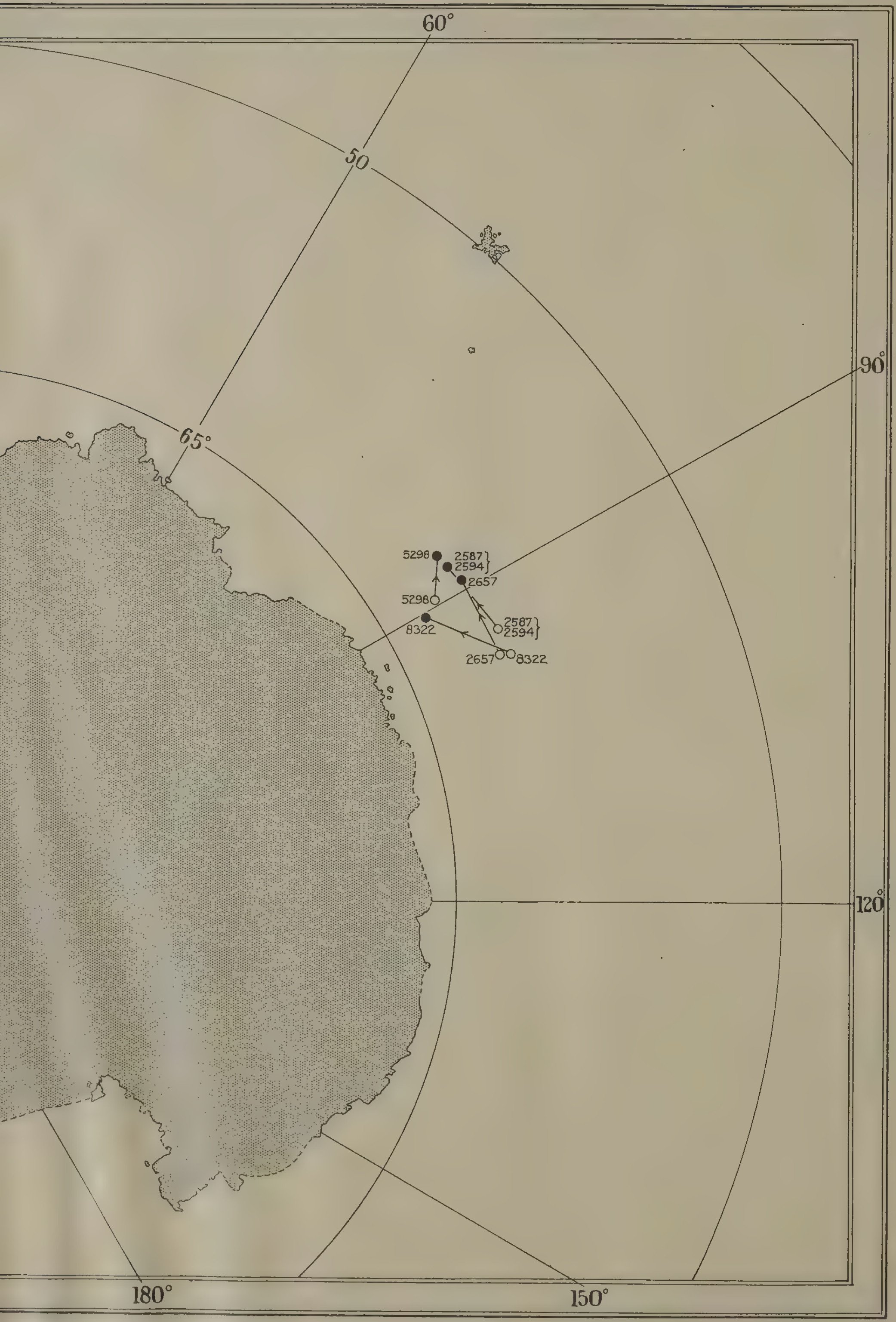

90°
110°
130°
0°
20 S
40°
60°
5360
5319
5307
5555
5566
8052
5403
8260
8260
5307
5566
5555
5319
5360
5403

and capture of ½-group whales.

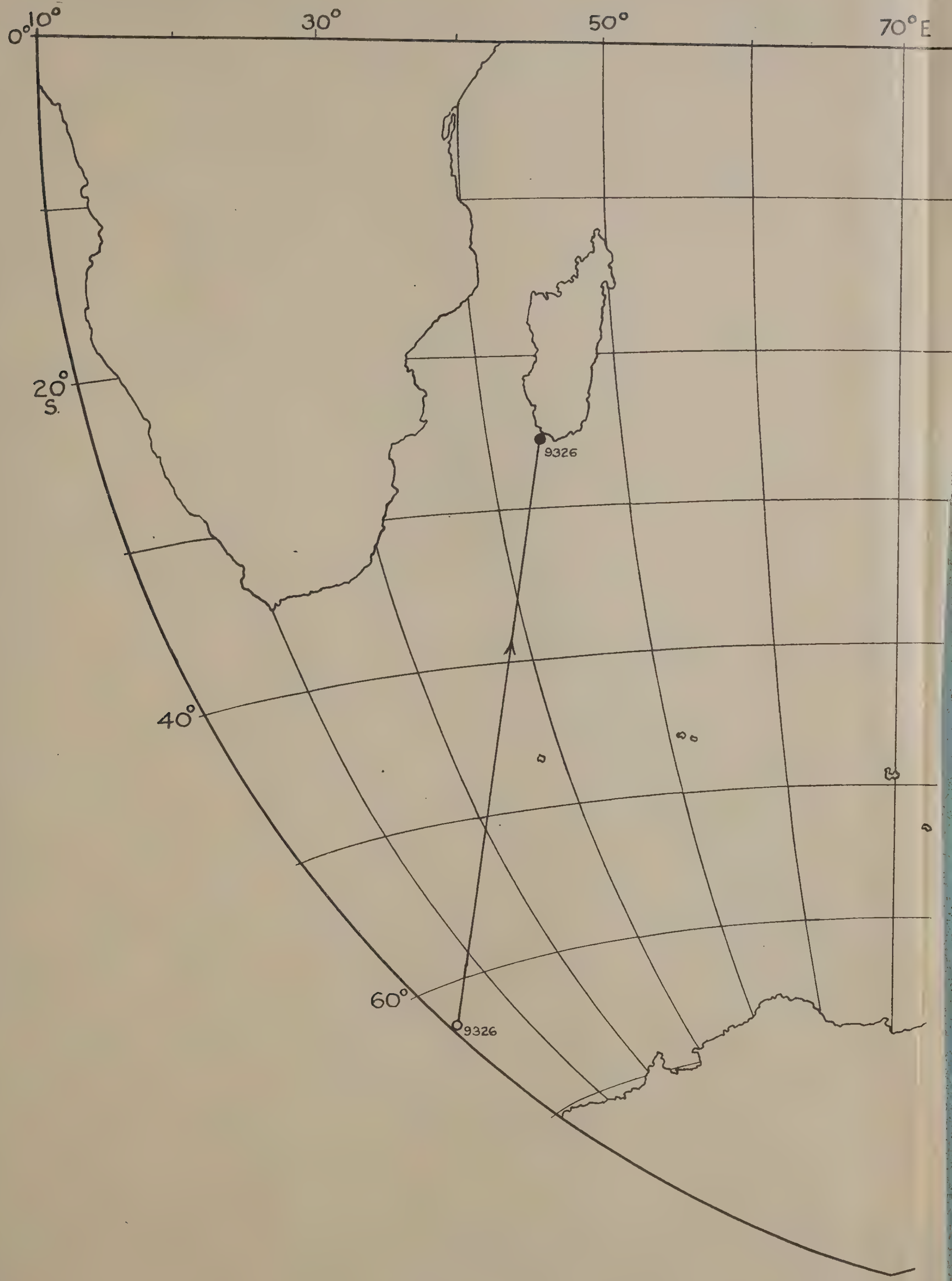

0°
30°E
2024
2024
30°
60°
90°
120°
150°

Humpback whales. Southern Ocean. Positions

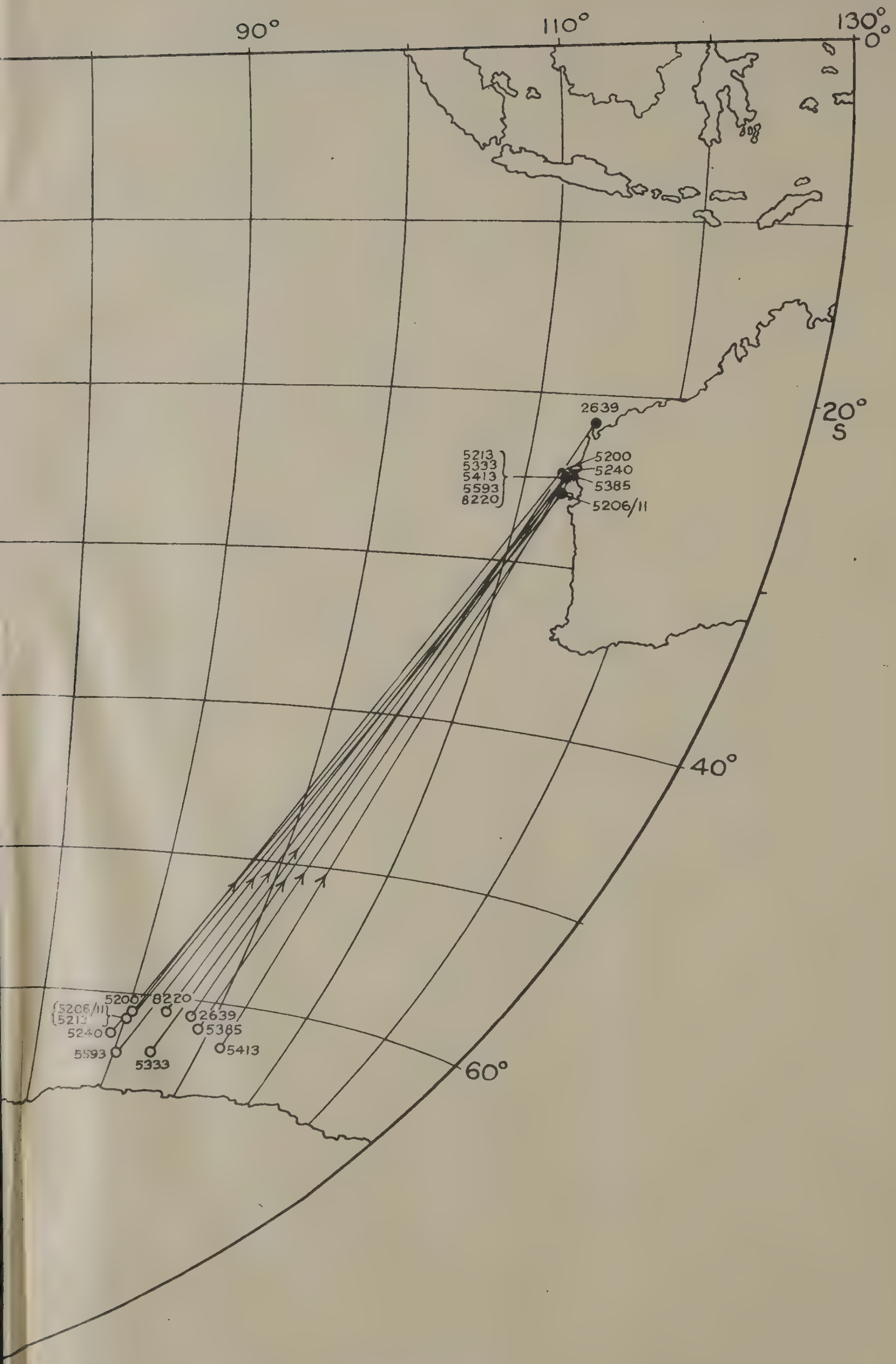
PLATE LXIV


60°
50
65°
90°
120°
180°
150°
5298
2587
2594
2657
5298
8322
2587
2594
2657
8322

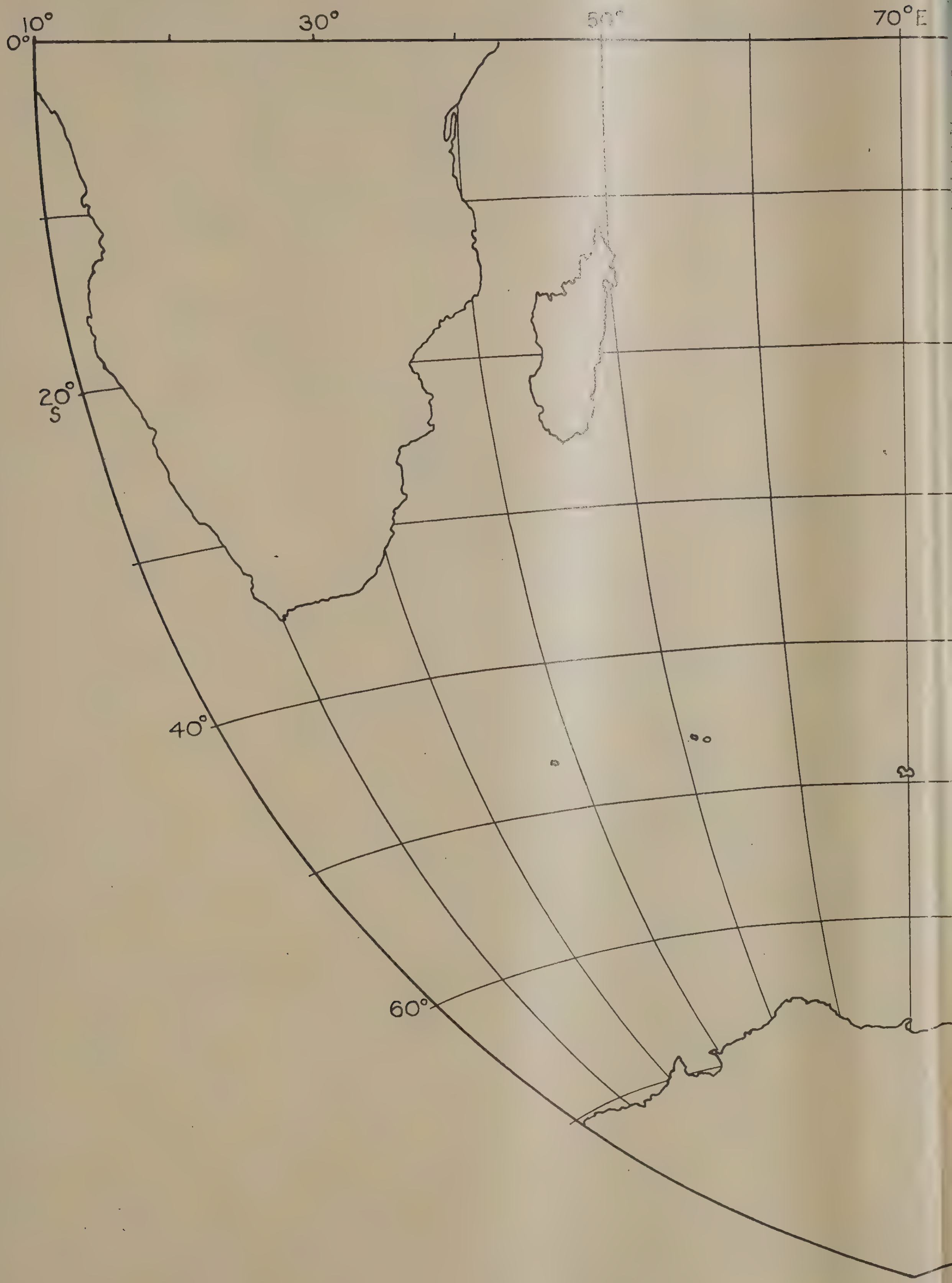
king and capture of 1-group whales.


0°
10°
30°
50°
70° E
20° S.
40°
60°
9326
9326

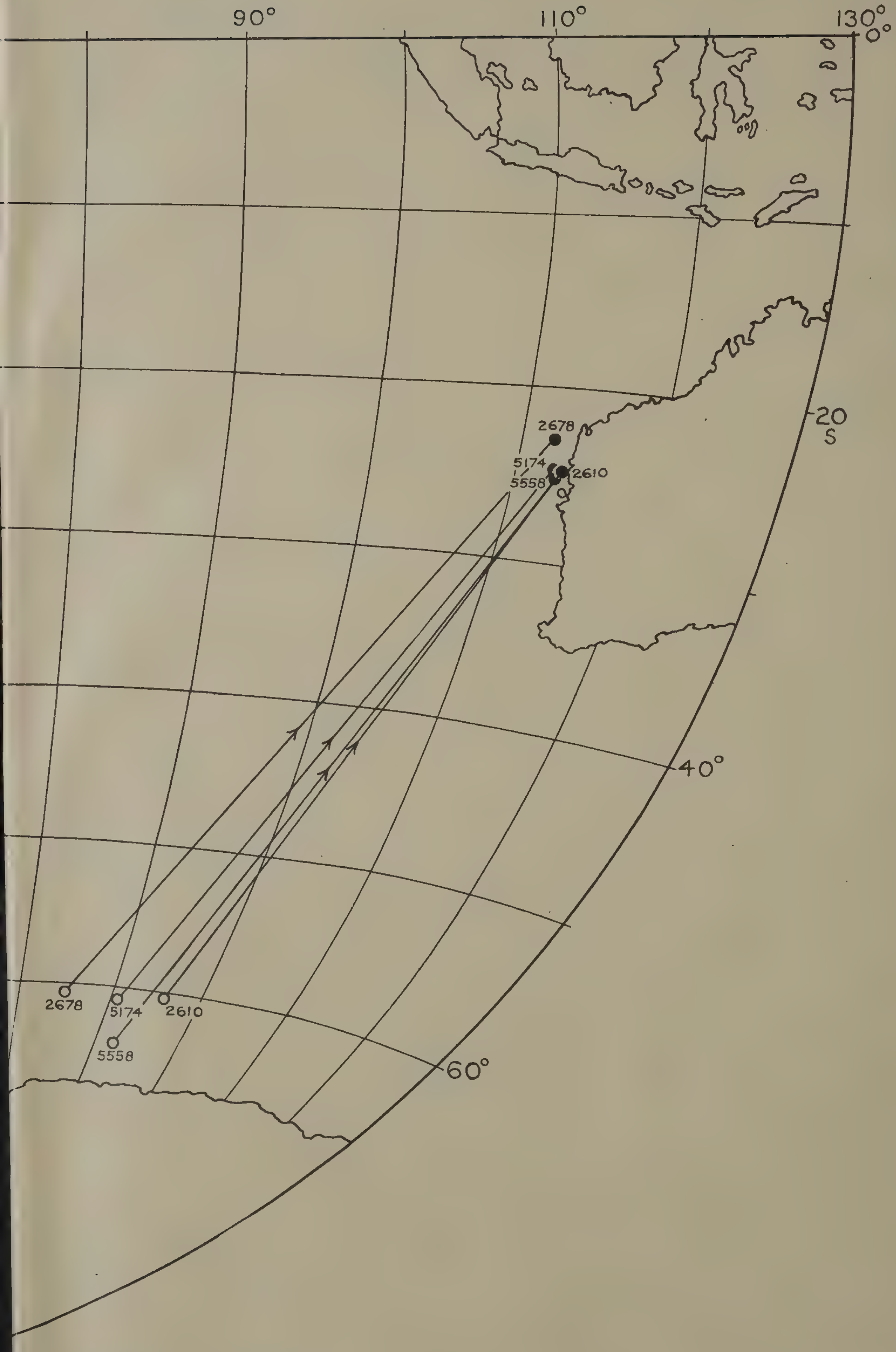
Humpback whales. Indian Ocean. Positions of


90°
110°
130°
0°
20°
S
40°
60°
2639
5213
5333
5413
5593
8220
5200
5240
5385
5206/11
5200
8220
5206/11
5213
5240
2639
5385
5593
5333
5413

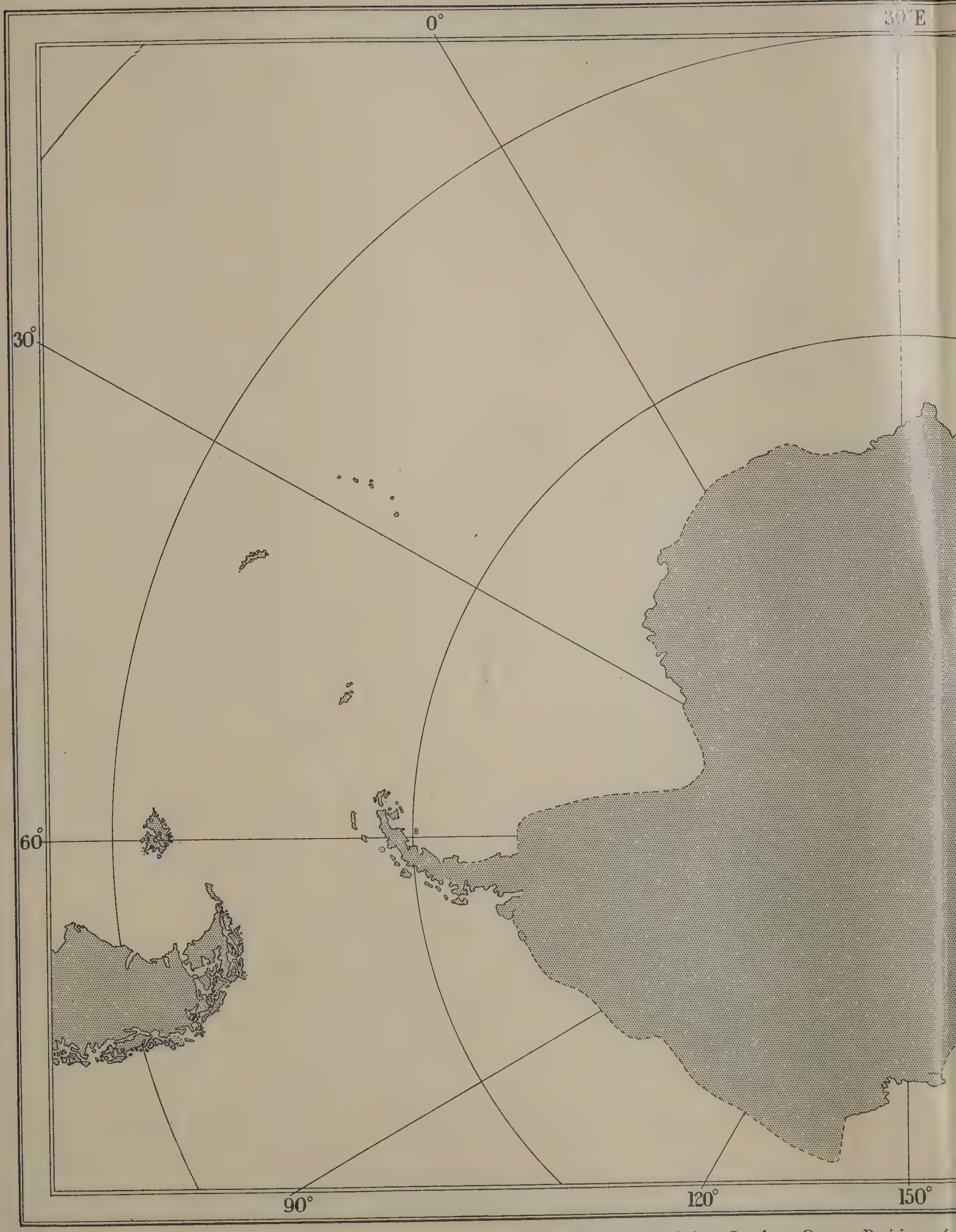
ing and capture of 1½-group whales.


10°
30°
50°
70°E
0°
20° S
40°
60°

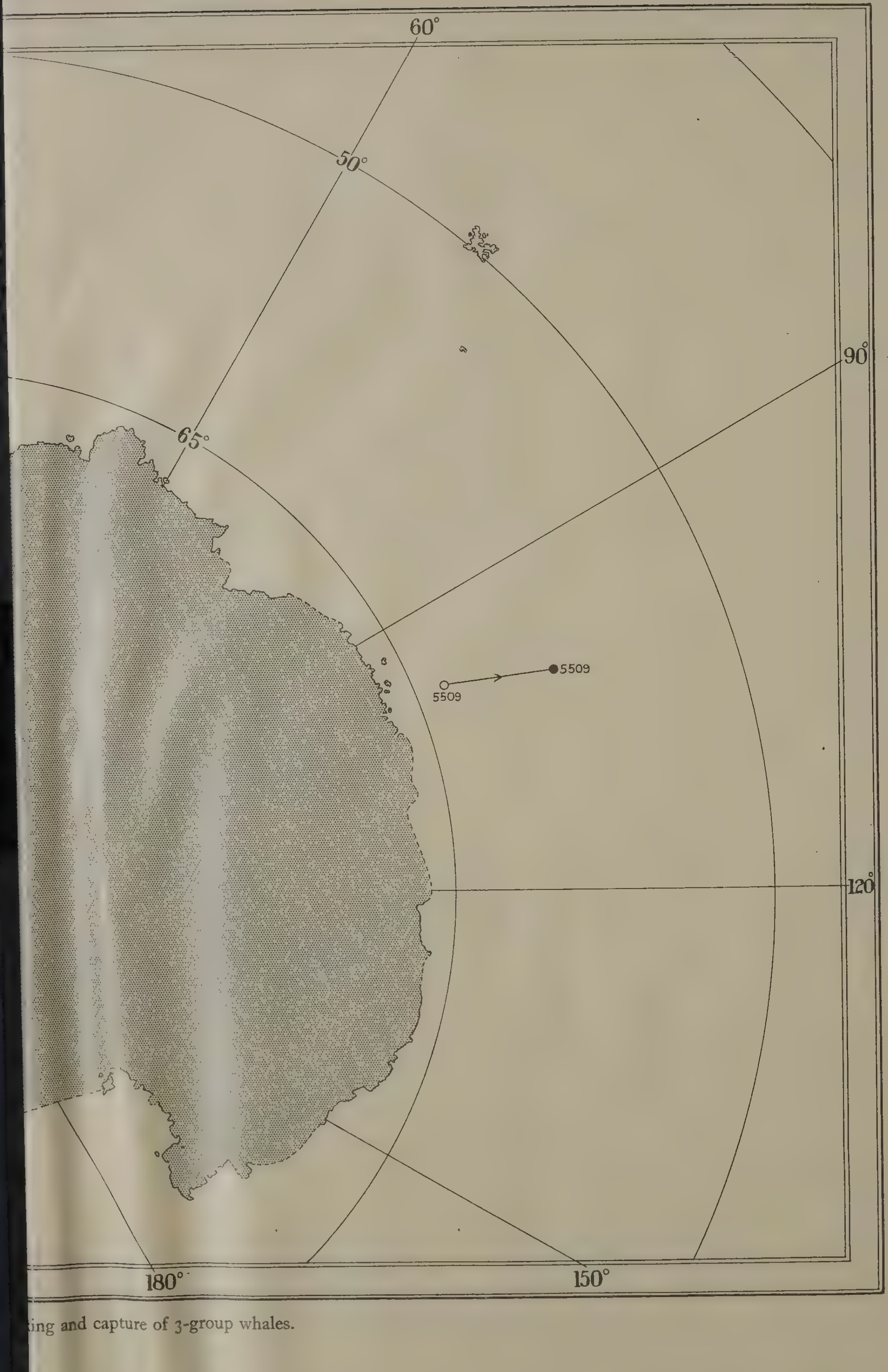
Humpback whales. Indian Ocean. Positions of


90°
110°
130°
0°
20
S
40°
60°
2678
5174
5558
2610
2678
5174
2610
5558

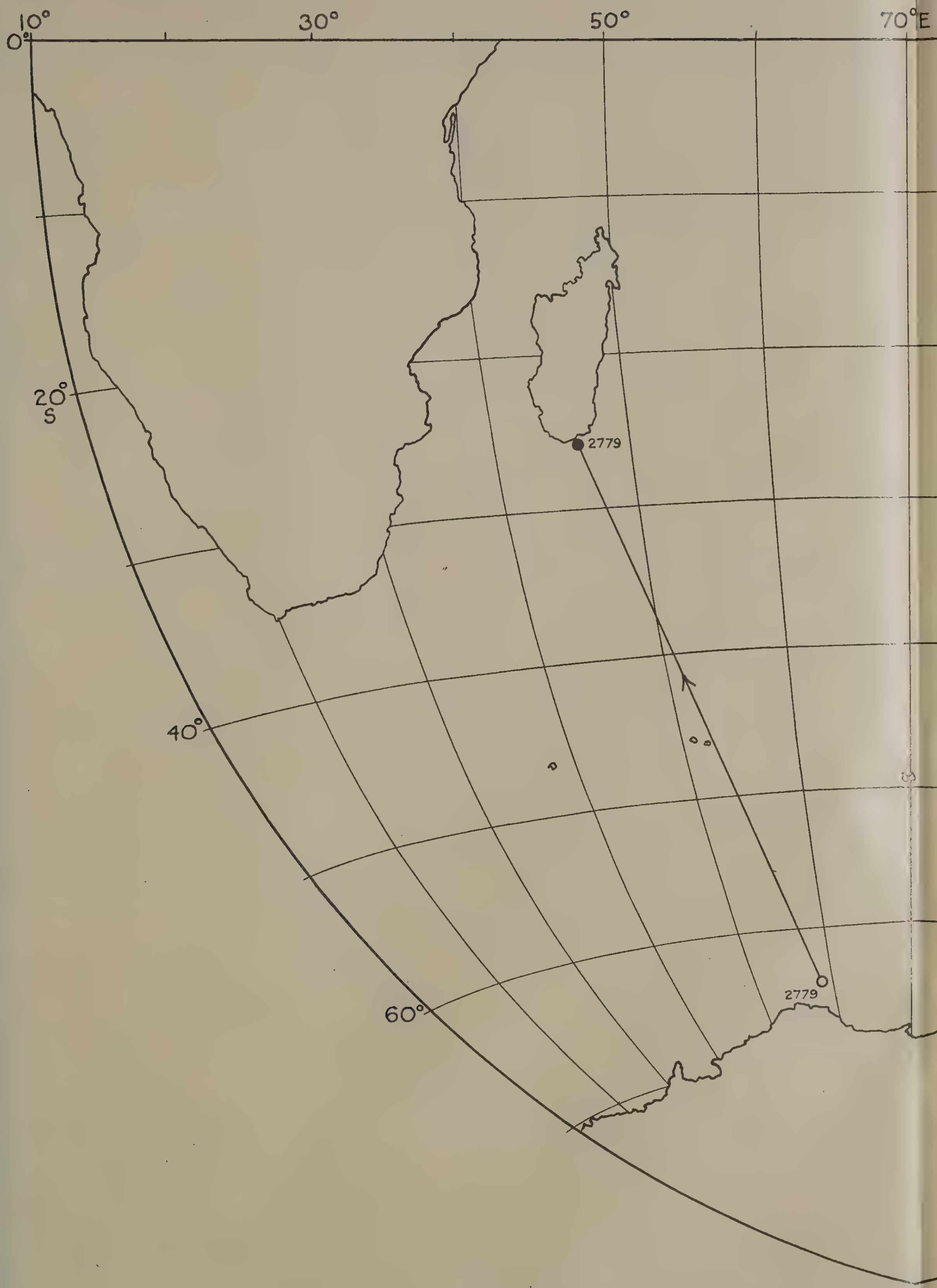
ng and capture of 2½-group whales.


0°
30°E
30°
60°
90°
120°
150°

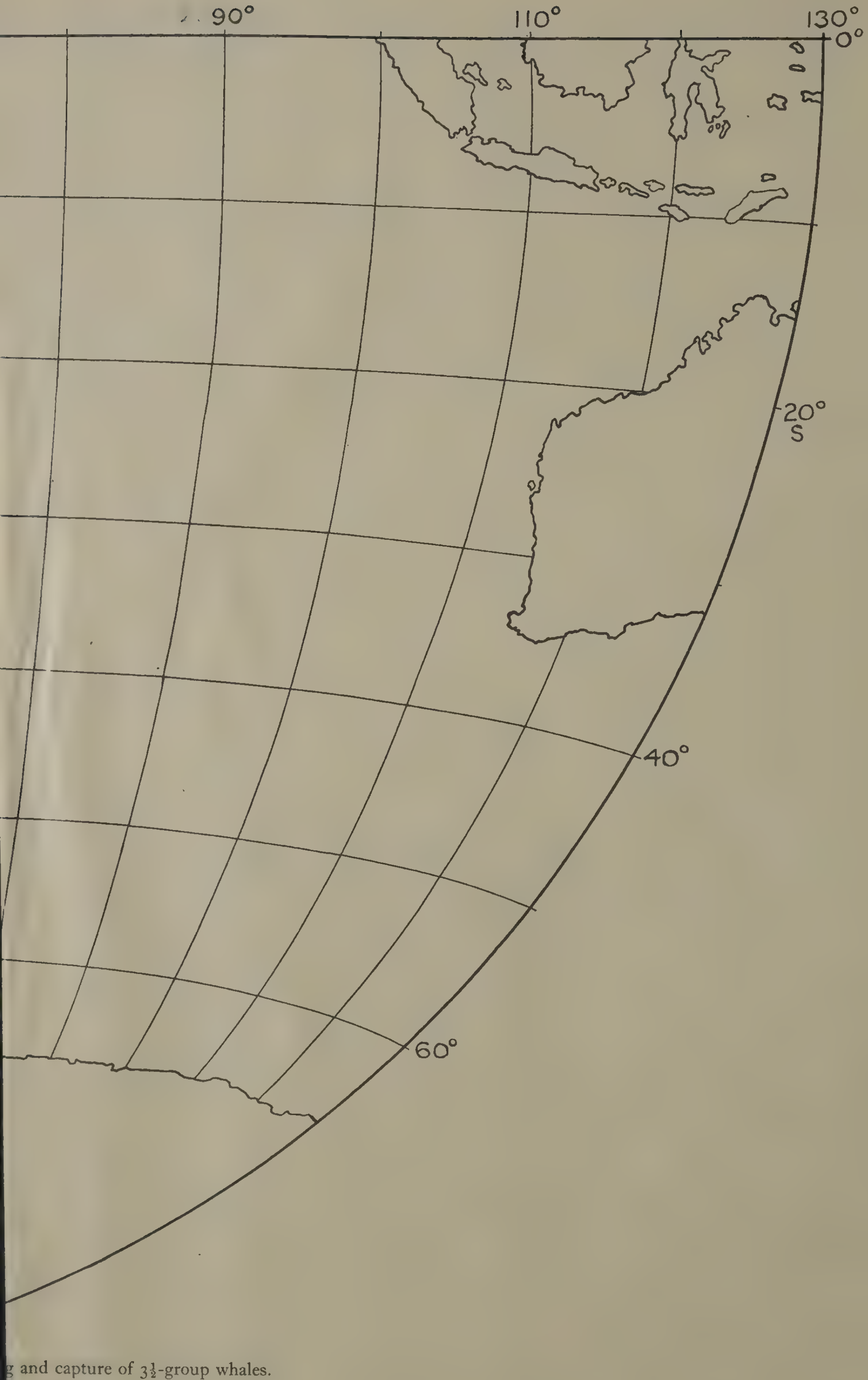
Humpback whales. Southern Ocean. Positions of


60°
50°
65°
90°
120°
150°
180°
5509
5509

ing and capture of 3-group whales.


10°
30°
50°
70°E
0°
20°
S
40°
60°
2779
2779

Humpback whales. Southern Ocean. Positions


90°
110°
130°
0°
20°
S
40°
60°

g and capture of 3½-group whales.

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DISTRIBUTION OF THE PACK-ICE IN THE SOUTHERN OCEAN

By

N. A. MACKINTOSH, D.Sc. and H. F. P. HERDMAN, M.Sc.

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DISTRIBUTION OF THE PACK-ICE IN THE SOUTHERN OCEAN

By N. A. Mackintosh, D.Sc. and H. F. P. Herdman, M.Sc.

(Plates LXIX–XCV)

INTRODUCTION

THE purpose of this paper is to furnish information on the limits of the Antarctic sea ice at different times of year, and it is hoped that it will be of some assistance both to the study of oceanographical problems in the Southern Ocean and to the navigation of ships in high southern latitudes. We have attempted little more than to plot a number of records of the observed position of the northern fringe of the pack-ice, and to indicate, so far as the data permit, in what latitudes the ice-edge is most likely to be found at different times of year. We have not set out to discuss the factors which control the distribution of the ice nor to describe the processes of its formation and disintegration.

It will be realized that this paper is only a preliminary consideration of a large and complex subject. The available observations are quite inadequate for a detailed account of the distribution and movements of the pack-ice as a whole, especially in the winter months, but the times and places at which additional records are most needed can be seen at once from the charts. However, we have been able to assemble a considerable number of records for the summer months from many parts of the Southern Ocean, and sufficient for the winter months to give at least a rough indication of the seasonal advance and retreat of the ice-edge.

There is very little published work on the broad distribution of the Antarctic pack-ice edge; in fact a paper by Hansen (1934) appears to be the only account of the varying limits of the pack-ice in any large part of the Southern Ocean. This is a short paper illustrated by a set of charts showing the positions of the ice-edge at different times on the southern whaling grounds in the seasons 1929–30, 1930–1, 1932–3 and 1933–4. These charts were based on the positions, at monthly or half-monthly intervals, of whaling factory ships working at the ice-edge, and they constitute a most valuable record of the changes in the distribution of the pack-ice in those four Antarctic summers. They only cover, however, the area between 40° W and 110° E and the period from October to March. Subsequently an *Atlas over Antarktis og Sydishavet* was compiled by Hansen and published by the Norsk Hvalfangernes Assuranceforening, and in this is included a chart showing the approximate mean positions of the ice-edge in November, December, January and March in all except the Pacific sector, and in January and March in the Pacific sector also. This again is derived mainly from records from the whaling fleet. So far as the whaling grounds are concerned it is presumably based on abundant material, but elsewhere, such as in the Pacific sector, the mean positions of the ice-edge are no doubt to be taken as very tentative.

CONSTRUCTION OF THE CHARTS

PLOTTED OBSERVATIONS OF ICE

The charts accompanying this report are primarily intended to show the seasonal variations in the position of the ice-edge, and they include records from every month of the year. In Plates LXXI to XCV each record is separately plotted, and the great majority are derived from the Discovery Committee's ships, the 'Discovery', 'Discovery II' and 'William Scoresby', and from a number of factory ships. We have to thank Capt. H. E. Hansen for very kindly providing us with a large body of data consisting of extracts from the logs of some of the factory ships for the seasons 1930–1, 1932–3, 1933–4, 1934–5 and 1935–6. These are more numerous than the observations of the Discovery Committee's ships, but the latter are better distributed in time and space, and include a number of winter observations. A small number of observations are added from miscellaneous sources where such records have helped to fill gaps in the above data. Among these are some unpublished records kindly supplied by Capt. Sverre Nielsen of ice conditions found by whalers approaching the South Shetlands at the beginning of the whaling season, certain observations of the 'Pourquoi Pas?' in the Bellingshausen Sea (see Bongrain, 1914, plate v), and ice conditions in the Ross Sea given in the *Antarctic Pilot*. In the charts separate symbols are used to distinguish the observations (*a*) of the Discovery Committee, (*b*) of factory ships, and (*c*) of other expeditions.

We have included in the charts only those observations in which not only the position of the ice-edge but also the date are known, for the mean latitude of the ice-edge may vary considerably even in the same month, and an undated record is of little value. Furthermore, the plottings are intended to represent the actual outer boundary of the pack-ice belt, and any records such as abstracts from logs in which it is merely stated that pack-ice is in sight are disregarded unless there is something to show that the ship was actually at or near the true ice-edge, and not some distance within an area, for example, of open drift ice.

Not all the accessible data have been used. It would no doubt be possible to obtain additional observations from factory ships, and a search throughout the reports of all Antarctic expeditions would enable us to plot a few more positions. These would, however, add little or nothing to the regions and times of year at which additional observations are most needed, and would multiply the records elsewhere to an extent which would make it difficult to plot separate observations on charts of the scale which we have found convenient for the purposes of this paper. In any more detailed description of ice conditions within a limited area no such records could of course be neglected.

Separate charts are given for nearly every month, but, since observations are scarce in the winter, May and June records are put together in Plates XCIII and XCIV and July and August in Plate XCV. For most months also (September to March) there are three semicircular charts covering different parts of the Antarctic, and overlapping each other by 60° of longitude. Thus, for instance, Plates LXXXIII, LXXXIV and LXXXV show all records made in January in whatever year, but the day of the month and the year are shown against each record. For example, in Plate LXXI, which shows September observations, a record of the ice-edge is plotted in 20° E and marked 30.38. This means 30 September 1938.

The latitude of the ice-edge varies to some extent in different years, but there is a much greater variation in different seasons of the same year, and it is for this reason that separate charts are given for each month and not for each year.

THE OBSERVED ABSENCE OF ICE

On each chart a line is drawn in red in what appears to be the mean position for the ice-edge for that month. In the interpretation of these charts it is important to remember that they show only the observed presence of ice and not, except in very few instances, its observed absence. In a really thorough determination of the mean position of the ice-edge full account should be taken of the occasions on which ships have steamed southwards and reached the land or turned away to the north without seeing any pack. Such negative observations would, however, be very difficult to trace. The charts do indicate one or two points (Plates LXXXIV, LXXXVI and LXXXIX) where the continental coast or barrier was found to be clear of ice, but there have, for example, been occasions when factory ships approaching the South Shetland Islands in October and November have reached the Bransfield Strait without encountering ice, although Plates LXXIV and LXXVII show that on other occasions the ice-edge in those months lay a considerable distance outside the islands (see p. 292). However, the scarcity of negative observations is perhaps less important elsewhere in the Antarctic, for whereas the South Shetlands always become ice-free in certain summer months the coasts of other parts of the Antarctic continent are probably seldom clear, and ships from which our records are taken are believed to have generally cruised southward until they found and recorded the ice-edge.

MONTHLY MEAN POSITION OF THE ICE-EDGE

The monthly mean position of the ice should, then, be placed a little farther south than the average position of the plotted records of ice observed to be present. The red line drawn on the charts is in any case only tentative. Where it is based on actual observations it is drawn as a continuous line, and where it is interpolated or filled in by analogy with other months it is drawn as a pecked line. In placing these lines we have been guided here and there by Hansen's charts, and the distribution of surface temperature, such as shown by Deacon (1937, p. 29), has occasionally been suggestive.

In Plates LXIX and LXX the mean position shown on the other charts are assembled, the summer and winter months being shown separately, and these give a general picture of the seasonal advance and retreat of the ice-edge. It will be understood that they represent the normal positions of the ice only so far as the available data indicate them, and are subject to modification in the light of additional observations.

THE ANTARCTIC ICE-EDGE

The Antarctic pack-ice generally has a well-defined northern boundary. A ship steaming southwards in the Southern Ocean will at most times and places pass through open water until close pack-ice comes in sight. That is to say, there is not usually a gradual transition from isolated streams of ice to close pack. Such conditions indeed may sometimes be found, but far more often the ice is first seen as a solid white line on the horizon which soon bars further progress to a ship not prepared to force a way through it, and if the ice is first seen as an isolated stream it can generally be assumed that the main body of the pack is not far off.

Open water may of course lie to the south of the ice-edge. It is well known that open water is expected to be found in summer beyond the belt of pack in the Ross Sea, and in the Atlantic sector more or less open water is formed about December in comparatively high latitudes, while a belt of pack still lies to the north. In the Weddell Sea conditions appear to vary very much from year to year, and the distribution of ice is not predictable in the present state of our knowledge. Little is really known of the interior of the ice belt, but it seems probable that as a general rule there is more ice than open water between the ice-edge and the shores of the Antarctic continent. This paper, however, is almost exclusively concerned with the position of the northern boundary of the pack.

The type of floes seen at the ice-edge varies with the time of year and to some extent with the locality. In spring and summer small floes and brash are commonly met with, though much larger floes are to be found a little distance within the ice beyond the action of the swell. In autumn and winter the outer fringe of the pack often consists of ice scum which merges into pancake ice which in turn gives way to more substantial floes. The thickness of the ice varies considerably in different localities. Floes which have drifted from the Weddell Sea tend to be hummocked, overridden and very heavy. In parts of the Pacific sector, where it appears that the ice may become locked in the position of growth for considerable periods, immensely thick floes are to be seen.

The ice-edge, however clearly demarcated, lies in a tortuous line, often with deep bays and with promontories which may extend some miles from the main body of the pack. In the charts accompanying this paper most of the records of the positions of the pack-ice are derived from isolated observations or a series of recorded positions. Occasionally, however, a ship has followed the course of the ice-edge and charted it in detail for a considerable distance. Thus the 'William Scoresby' in October 1928, charted the outline of the pack east of South Georgia, and in Plate LXXIV, between 28° and 32° W, the winding course of the ice-edge is well exemplified. The 'Pourquoi Pas?' similarly followed the edge of the pack for a great distance in the Bellingshausen Sea, and this record is plotted in Plate LXXXV between 76° and 123° W.

There are various signs by which a ship steaming southwards may be warned of the proximity of the pack before the ice itself is in sight. The Antarctic Petrel is nearly always seen about 400 miles or less from the ice-edge. The appearance of the Snow

Petrel, an abrupt drop in the sea temperature of about 1–1·5° C., and a sudden decrease in the swell indicate that the pack is within a few hours steaming. These phenomena are seldom absent and are usually noticed before ice blink is visible. The blink is sometimes not seen until the ice is very close, but it is often a most valuable indication of the local disposition of the pack. These signs of the approach to pack-ice are described by Lieut. L. C. Hill, R.N.R. (commanding officer of the 'Discovery II', 1936–9) in Supplement No. 7 to the *Antarctic Pilot*. He mentions also the Antarctic Tern, which was only seen at the ice-edge.

SEASONAL DISTRIBUTION OF THE ICE-EDGE

GENERAL FEATURES

The ice extends farthest north in late winter and spring, its edge lying in much the same position in July, August, September and October. During the summer the ice-edge retreats southward and during the winter it advances north again. The range of this advance and retreat varies considerably in different parts of the Antarctic. It is greatest in the Atlantic sector and probably least in the Bellingshausen Sea, though in the vicinity of Adélie Land also there appears to be a comparatively small range.

The ice generally lies farthest south about February and March. Parts of the continental coast may be found clear of ice as early as January. Thus the 'Discovery II' on 16 January 1938 approached the coast of Adélie Land without seeing pack. But the ice is probably at its minimum at the end of February and beginning of March, and then is perhaps the best chance of finding the coast clear of ice. Except on the Pacific side and perhaps on the west side of the Weddell Sea, it is probable that nearly all parts of the continental coast or fixed barrier are free of ice from time to time in the late summer. In the Pacific sector between about 75° and 140° W the ice seems more stagnant and no ship has penetrated it to the land, although several have attempted to do so. At the end of the winter when the ice lies farthest north, its edge in the Scotia Sea region runs from south-west to north-east and reaches to about 55° S to the north of the South Sandwich Group. This latitude is maintained to about 20° E, but beyond that it falls away more and more to the south. East of 110°, off Adélie Land and the Ross Sea and in the Pacific sector, it is possible that the ice-edge is always south of 60° S except perhaps to the north-east of the Ross Sea, where it tends to reach farther north.

Plate LXIX gives an indication of the rate at which the ice-edge retreats during the summer, and it will be seen that in the Atlantic sector there is a rapid break up in December. This will be described in more detail below. Plate LXX gives a tentative representation of the advance of the ice-edge in winter, but it is based on scanty material.

The latitude of the ice-edge on any given date of course varies a good deal from year to year. The extent of this variation is well shown in the charts except in those months in which observations are very scarce. We are not making here any detailed comparison of the ice conditions in different years. The charts speak for themselves in this respect, but it should be remembered that the "spread" of the plottings in any one month may be due as much to the difference between the beginning and end of the month as to the difference between different years. In December, for example, it will be seen that the more northerly positions are mostly recorded early in the month, and the more southerly positions towards the end of the month.

The Weddell Sea has an important effect on the distribution of ice in the Atlantic sector. The low latitude reached by the ice-edge between 30° W and 20° E may be ascribed to the flow of cold water from the Weddell Sea which exerts an influence far to the east, and maintains a belt of ice in this region for some time after the pack has begun to melt and break up farther south. In the Weddell Sea itself the distribution of ice is very variable and little understood. The Ross Sea, which is shallow and has a less effective current system, has comparatively little influence on the ice beyond its immediate neighbourhood.

SEPTEMBER (PLATES LXXI–LXXIII)

Observations in this month are scarce, but the ice is always far to the north. The 'Discovery II' found the ice-edge north of the South Shetlands and South Orkneys in 1934 (see Plate LXXI), and there are three records in about 55° S between South Georgia and 20° E. The only other record is to the north-east of the Ross Sea (about 62° S). All these observations were made by the 'Discovery II' or 'William Scoresby'.

OCTOBER (PLATES LXXIV–LXXVI)

There are more data for this month, especially between 0° and 10° E, and some records from factory ships are included. The three observations close to the South Shetlands (1911, 1926 and 1930) probably lie near the mean position of the ice-edge at this time of year, but it appears that in some years (e.g. 1910 and 1924) factory ships reached the Bransfield Strait in October without meeting pack-ice. (An account of ice conditions in the Bransfield Strait is given by Clowes, 1934, p. 59). In October 1930, the ice lay very near South Georgia, but the ice conditions in that spring were exceptional. Between 30° W and 20° E the October positions on the average resemble those for September. There are some useful observations by factory ships between 77° and 98° E, and in 117°–127° E the ice was found well to the south in 1930. There are no observations in the Ross Sea and greater part of the Pacific sector. The ice plotted in the Bellingshausen Sea in Plates LXXIV and LXXVI (1932 and 1934) almost certainly lies south of the normal position for mid-October. Both observations were made at the end of the month.

Little difference can be distinguished in the latitude of the ice-edge in September and October, and the lines showing what is here assumed to be the mean position in the two months are therefore drawn to coincide (see Plates LXIX and LXX).

NOVEMBER (PLATES LXXVII–LXXIX)

For this month there are records from nearly all longitudes. The only considerable gap is on the Pacific side between 120 and 180° W. There is a tendency for the ice to lie on the whole a little south of its position in September and October. In 1914 and 1931 ice lay well outside the South Shetlands, but in some other years (e.g. 1908, 1912, 1913, 1922 and 1924) some factory ships entered the Bransfield Strait without hindrance. The ice conditions are variable here, but it seems that the edge more often than not lies outside the South Shetlands in November. In the exceptional spring of 1930 ice was still to be found to the east and a little to the north of South Georgia, but in other years it lay considerably farther south. East of 20° W the records are well distributed, and the normal position of the ice-edge is fairly clear to 120° E. In the Adélie Land, Ross Sea, and Western Pacific regions there is little to go on, but a useful observation was made in 1928 in 170° E (Plate LXXVIII). In the Eastern Pacific sector (Plate LXXIX) the 'Discovery II' found ice in November 1934 about 66° S.

DECEMBER (PLATES LXXX–LXXXII)

There is a wealth of data for this month. In the region south of South Africa rapid changes take place, and large tracts of pack begin to break up and melt. The South Shetlands are usually clear of ice. Between 30° W and about 30° E the ice-edge is still in a low latitude, but warmer water farther south causes the central part of the ice belt to break up, leaving an outer zone which also begins to disintegrate. Hansen (1934), writing of this region, says: "...from December onwards the [whaling] expeditions force their way southwards through the pack-ice until they emerge into comparatively open water round about 60° S. The more continuous pack-ice is seldom met with then until the zone of the pack-ice along the land is reached. There are thus two zones of pack-ice when the season has advanced as far as this: an inner zone along the land, drifting westwards, and an outer zone drifting eastwards....At about the turn of the year the outer zone of pack-ice, at any rate the portion of it which lies to the east of the South Sandwich Islands, disappears (melts). Before melting, the zone of pack-ice usually breaks up in several places, with the result that it divides into large drifting islands of pack-ice."

Plates LXXX and LXXXI give a fairly clear indication of the conditions as far as 110° E. The two zones described above are not found east of 40° E, but there is a considerable retreat to the south and it will be seen that the more northerly observations are generally near the beginning of the month, and the more southerly towards the end. We have no records between 110° and 150° E, but there are several observations in the Ross Sea, some of which are derived from the *Antarctic Pilot* (1930, pp. 151, 152). Here conditions are rather variable, but it is well known that a ship penetrating the ice belt at this time of year will normally find open water in the southern part of the sea. The 1841 record in 148° W is probably farther north than the normal. There are no data from the Pacific sector except in the Bellingshausen Sea where the ice now lies well to the south.

JANUARY (PLATES LXXXIII–LXXXV)

The Bransfield Strait is now clear of ice, and much of the west coast of Graham Land may be free. Conditions are uncertain in the Weddell Sea, but streams of heavy ice may be expected around 60° S west of about 10° W. Farther east the "outer zone" of ice has broken up and open water is found for a long distance to the south. The factory ships at this time tend to concentrate in the vicinity of Enderby Land, and here large numbers of records are available. The conditions are also well shown as far east as 120° E. In 140° E the 'Discovery II' found open water off Adélie Land in January 1938. Conditions in the Ross Sea again are a little uncertain, but the 1936 records suggest that the ice is rapidly diminishing in this month. The Pacific sector is well covered by observations of the 'Discovery II', 'William Scoresby' and 'Pourquoi Pas?', the last-named ship having followed the ice-edge continuously from about 76° to 122° W.

FEBRUARY (PLATES LXXXVI–LXXXVIII)

Ice is still found on the north side of the Weddell Sea. East of 20° W it is generally a little farther south than in January. There are plenty of records as far as 105° E, but little thereafter. There are few ice observations in the Ross Sea, but there is a good chance of finding clear water here in February. In the Pacific sector the ice has generally been found a little farther south than in January, and the ice found by the 'Discovery II' in 1938 in about 68° S, 160° W seems unusually far north.

MARCH (PLATES LXXXIX–XCI)

In March the ice-edge is in much the same position as in February, but in at least some regions it seems to lie a little farther south. There is probably much open water in the Weddell Sea, and in 0–3° E the 'Discovery II' found open water to the barrier on 4 and 5 March 1939. Eastwards from this point observations extend almost to the Ross Sea. Probably the ice is patchy, with parts of the coast accessible. We have no records of pack-ice in the Ross Sea for this month, and it may be that there is normally continuous clear water to the barrier. In the Pacific sector conditions seem very similar to those of February, and the mean position of the ice-edge is taken to be the same.

APRIL (PLATE XCII)

From April onwards observations of the pack-ice are very scarce, and we have only those made by the Discovery Committee's ships. In this month there are several records in the Orkney-Shetland region and three usefully spaced observations between 0° and 50° E. There is nothing in the Australian and Pacific sectors, but the observations we have clearly indicate that the ice-edge lies farther north than in March, but not much farther.

MAY AND JUNE (PLATES XCIII, XCIV)

There are only two records in May, one in 40–45° E and one in 130° E. Here again there are signs of a farther advance to the north. In June again there are only two records, one from 0° to 17° E and one from 154° to 159° E. Both indicate that the ice has made a considerable advance towards the low latitudes occupied in spring.

JULY AND AUGUST (PLATE XCV)

Of the five records in July and August four are derived from the series of repeated cruises made by the 'Discovery II' in various months between July 1938 and March 1939. In July the ice was found very slightly farther north than in August, but it is not likely that this is the normal condition, for in September (Plate LXXI) the ice-edge was still farther north. Fluctuations in the winds and currents must often cause temporary changes in the latitude of the ice-edge, and in the absence of better data we must assume that it lies in about the same latitude in July and August.

From the above notes it will be seen that although the observations are inadequate for a completely reliable estimation of the normal position of the ice-edge in each of the winter months, the available records are just sufficient, if compared month by month, to show a fairly steady advance to the north from about March to July, and to give a rough idea of the latitude in which the ice-edge is likely to be found in any particular month.

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NOTES ON THE CHARTS

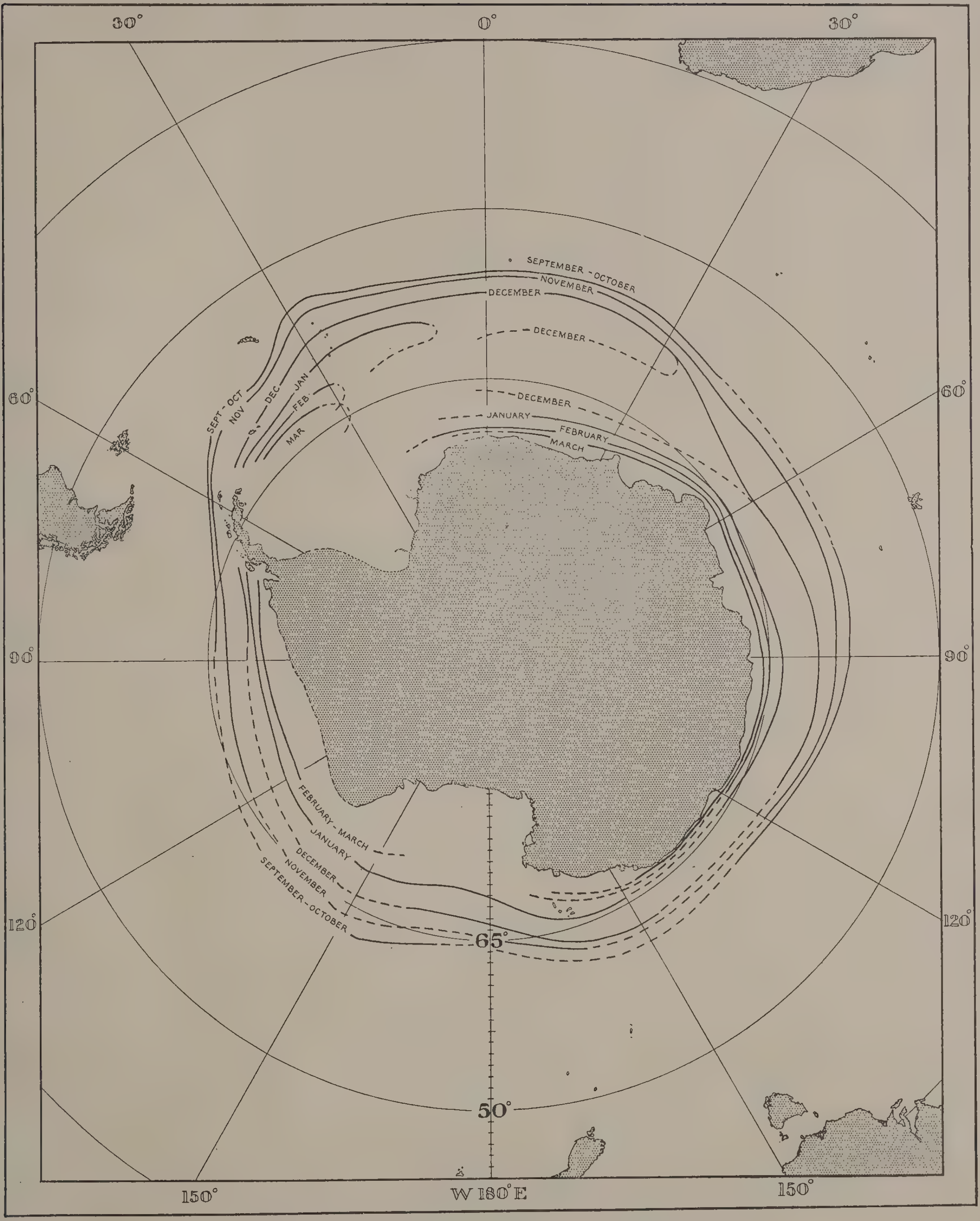
Plate LXIX shows the apparent mean position of the ice-edge in the summer months and Plate LXX in the winter months. Plates LXXI–XCV show the observed positions of the ice-edge in different months, and for most months there are three overlapping charts which cover different parts of the Antarctic.

Red lines indicate the assumed mean position of the ice-edge for the month in question.

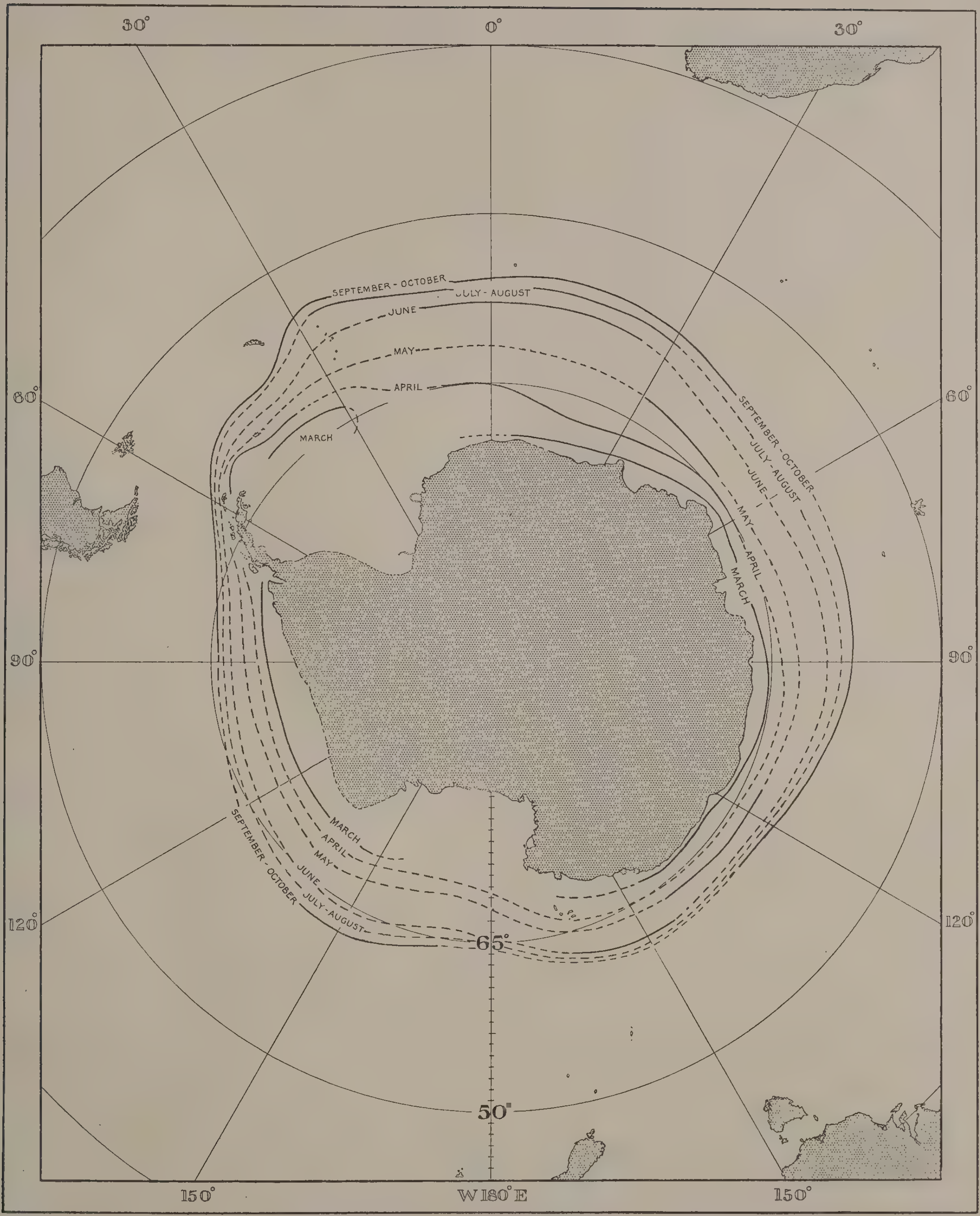
Lines with different types of hatching are used to distinguish the ice-edge positions observed by the Discovery Committee's ships, by factory ships, and by other expeditions. Figures adjacent to the hatched lines indicate the date and year, e.g. in a chart of September observations "30.38" would mean 30 September 1938. The letters "P.A." following such figures mean position approximate.

It is to be noted that the charts show the observed positions of the ice-edge, but not, except in a few instances, its observed absence.

Place names are shown only in the charts for September (Plates LXXI–LXXIII).


30°
0°
30°
60°
60°
90°
90°
120°
120°
150°
W 180° E
150°
65°
50°
SEPTEMBER - OCTOBER
NOVEMBER
DECEMBER
DECEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
SEPT - OCT
NOV
DEC
JAN
FEB
MAR
FEBRUARY - MARCH
JANUARY
DECEMBER
NOVEMBER
SEPTEMBER - OCTOBER

Apparent mean positions of the ice-edge in the summer months.


30°
0°
30°
60°
60°
90°
90°
120°
120°
150°
W 180° E
150°
65°
50°
SEPTEMBER - OCTOBER
JULY - AUGUST
JUNE
MAY
APRIL
MARCH

Apparent mean positions of the ice-edge in the winter months.

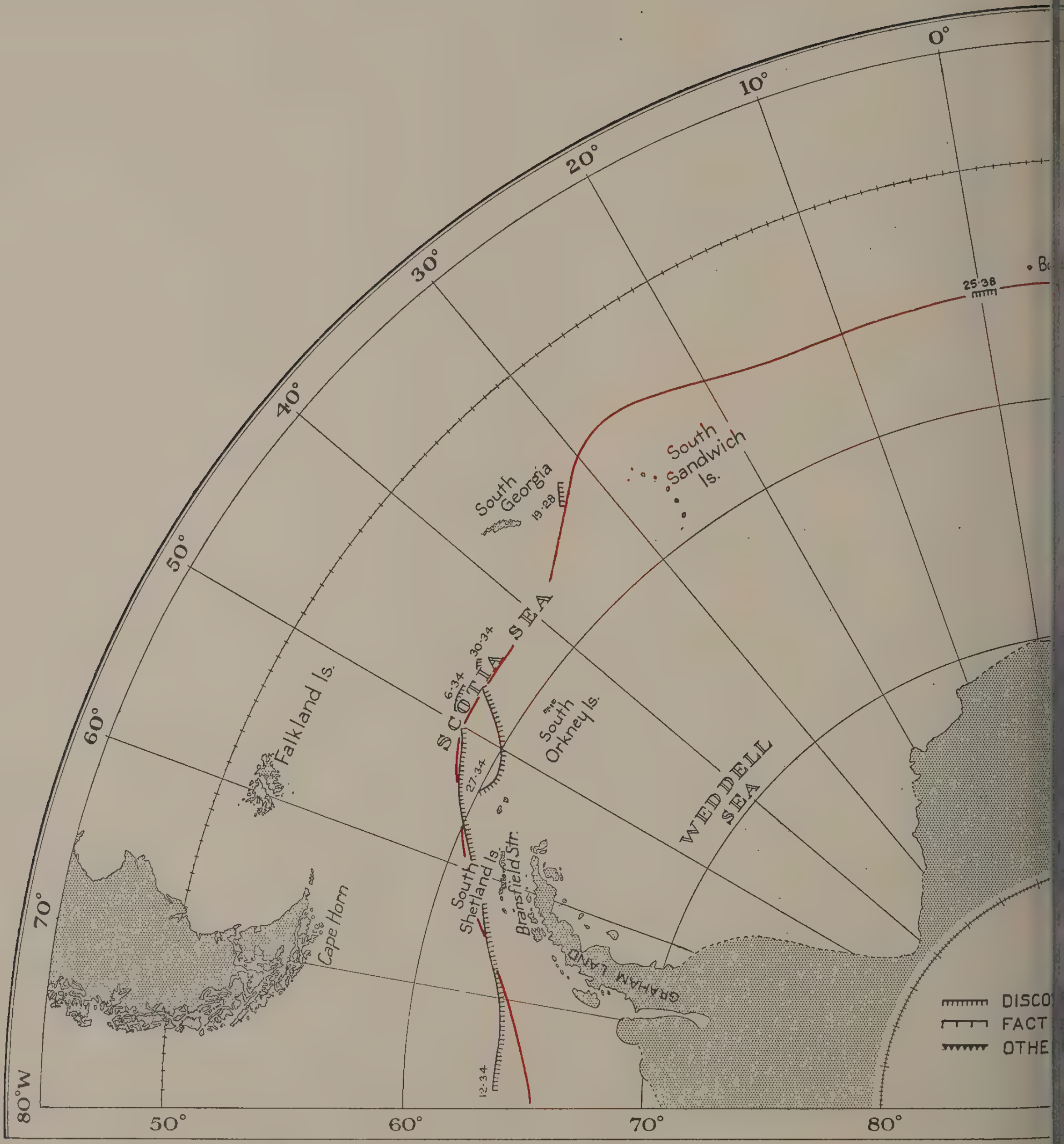
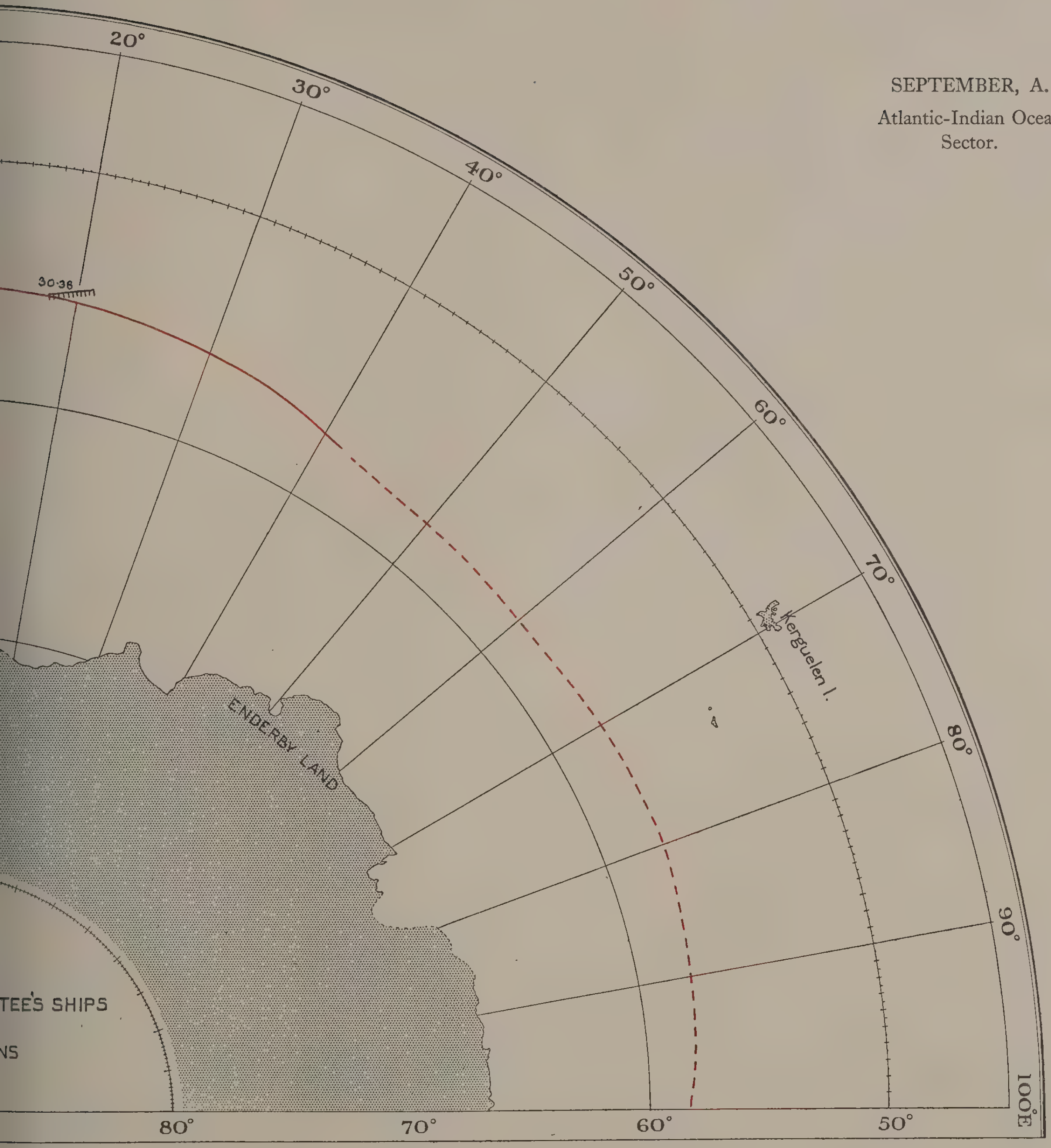

0°
10°
20°
30°
40°
50°
60°
70°
80°W
50°
60°
70°
80°
25·38
South Georgia
19·28
South Sandwich Is.
SCOTIA SEA
30·34
6·34
27·34
Falkland Is.
South Orkney Is.
WEDDELL SEA
South Shetland Is.
Bransfield Str.
Cape Horn
GRAHAM LAND
12·34
DISCO
FACT
OTHE

PLATE LXXI

SEPTEMBER, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
30·38
Kerguelen I.
ENDERBY LAND
TEE'S SHIPS
NS
80°
70°
60°
50°

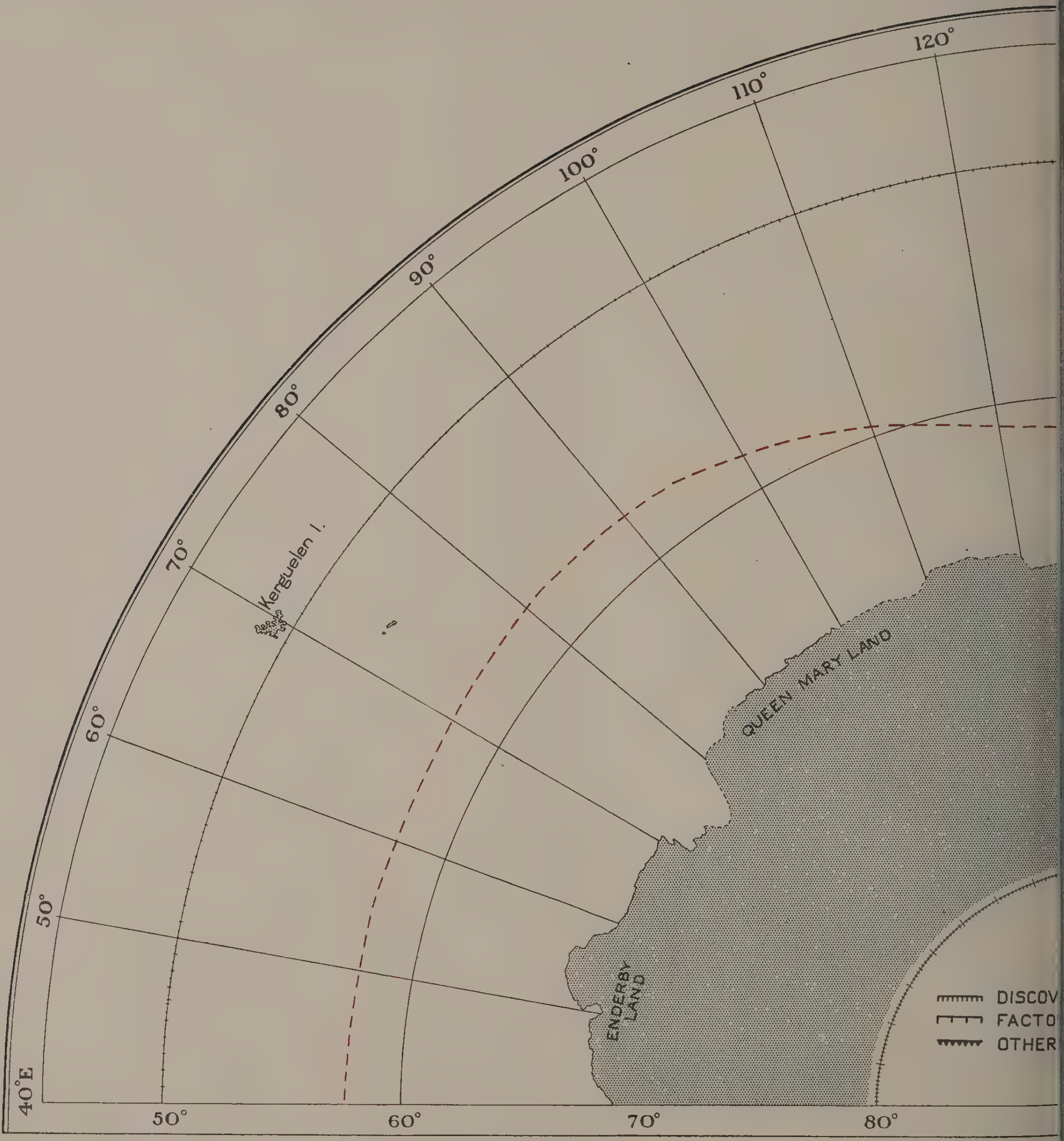
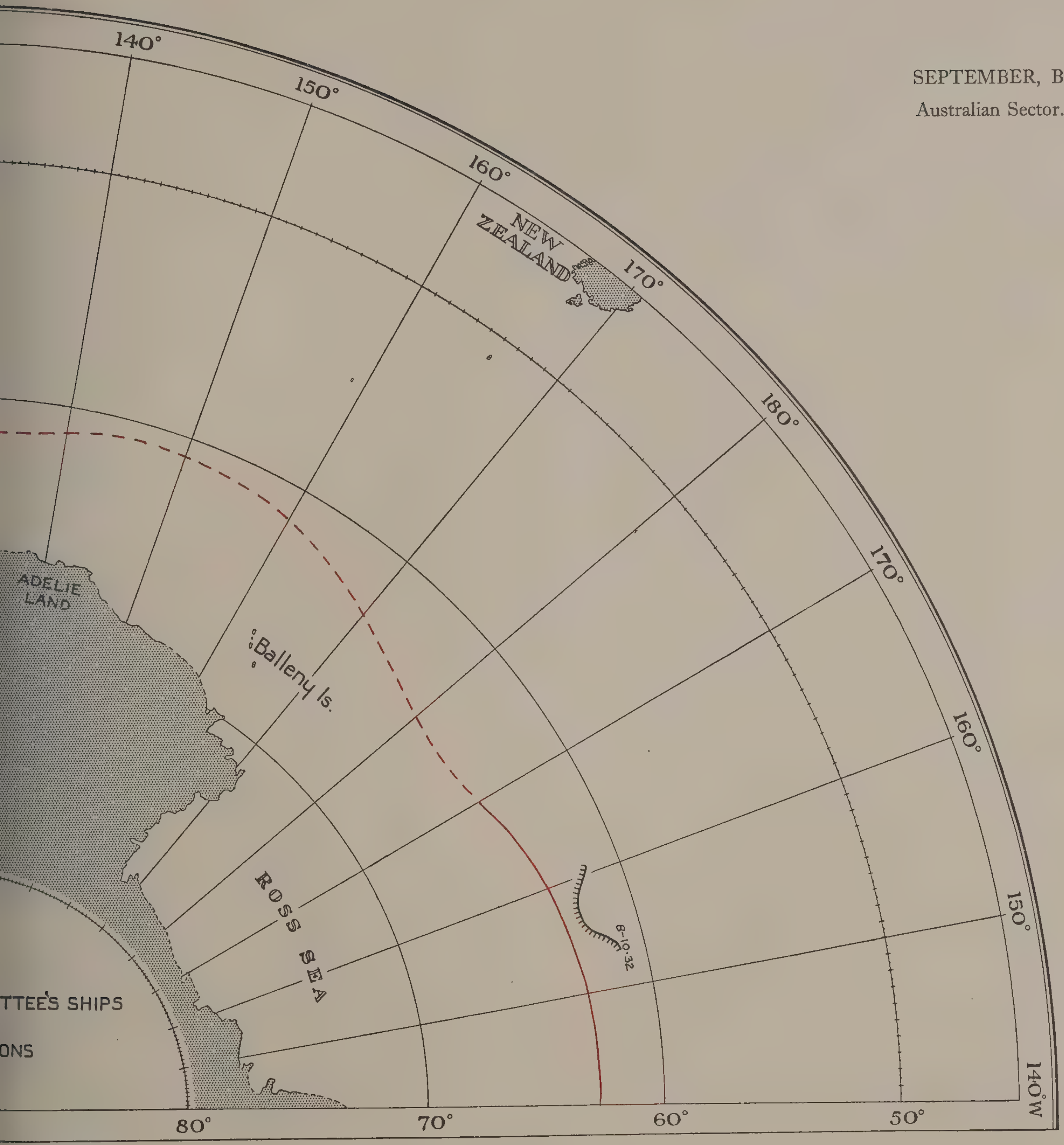

120°
110°
100°
90°
80°
70°
60°
50°
40°E
50°
60°
70°
80°
Kerguelen I.
QUEEN MARY LAND
ENDERBY LAND
DISCOV
FACTO
OTHER

PLATE LXXII

SEPTEMBER, B.
Australian Sector.


140°
150°
160°
170°
NEW ZEALAND
180°
170°
160°
150°
140°W
ADELIE LAND
Balleny Is.
ROSS SEA
8-10-32
TTEE'S SHIPS
ONS
80°
70°
60°
50°

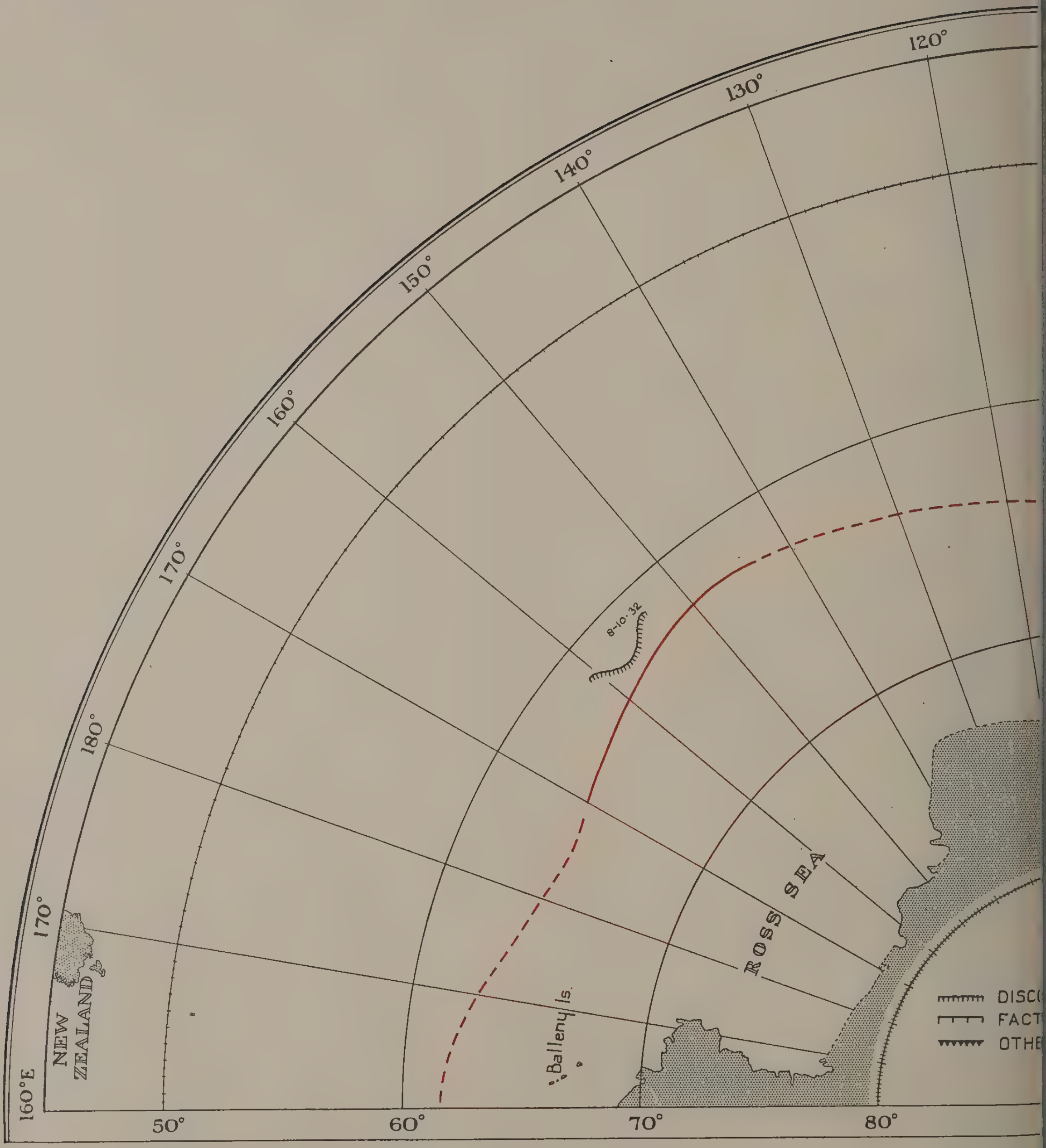
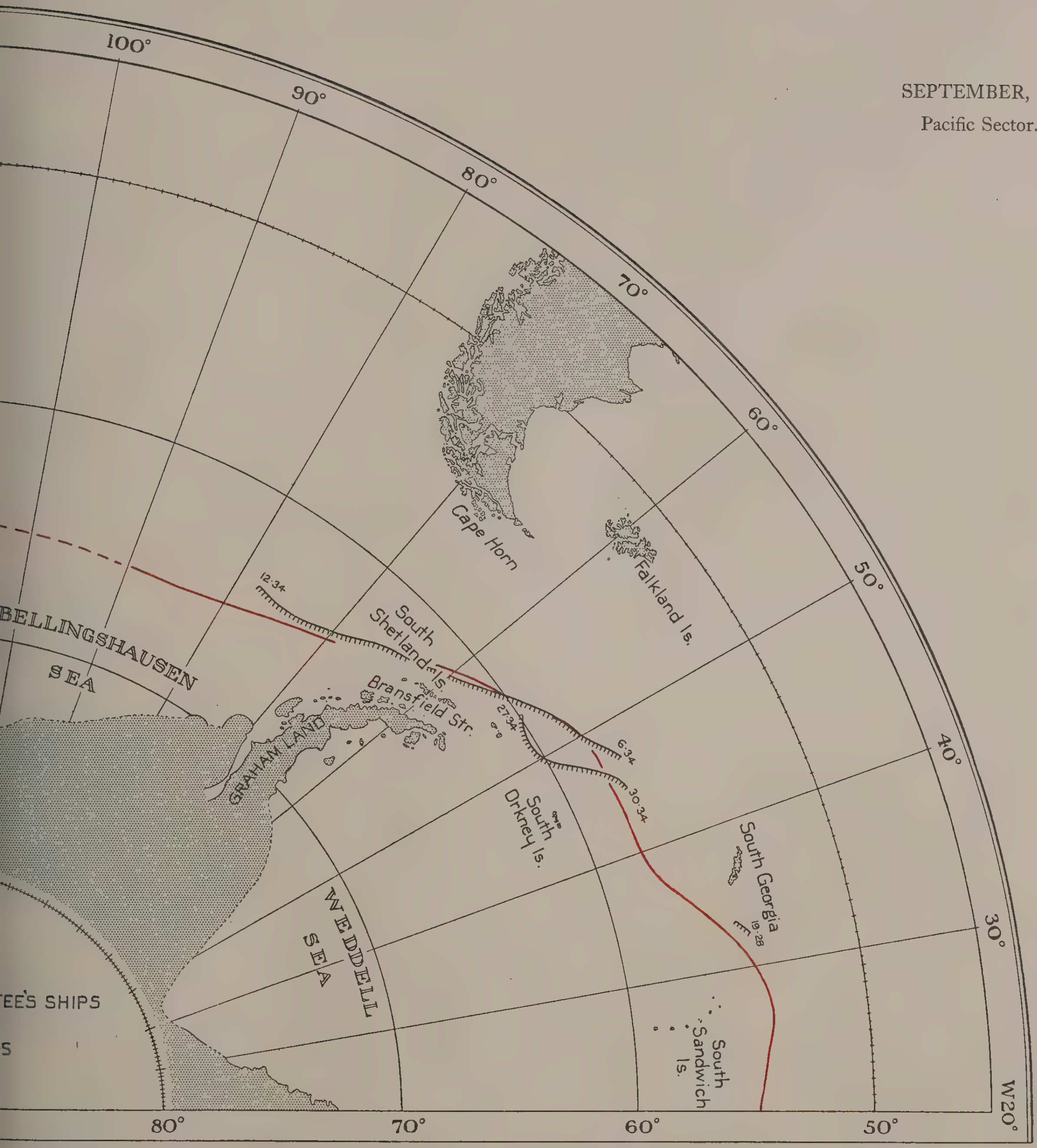
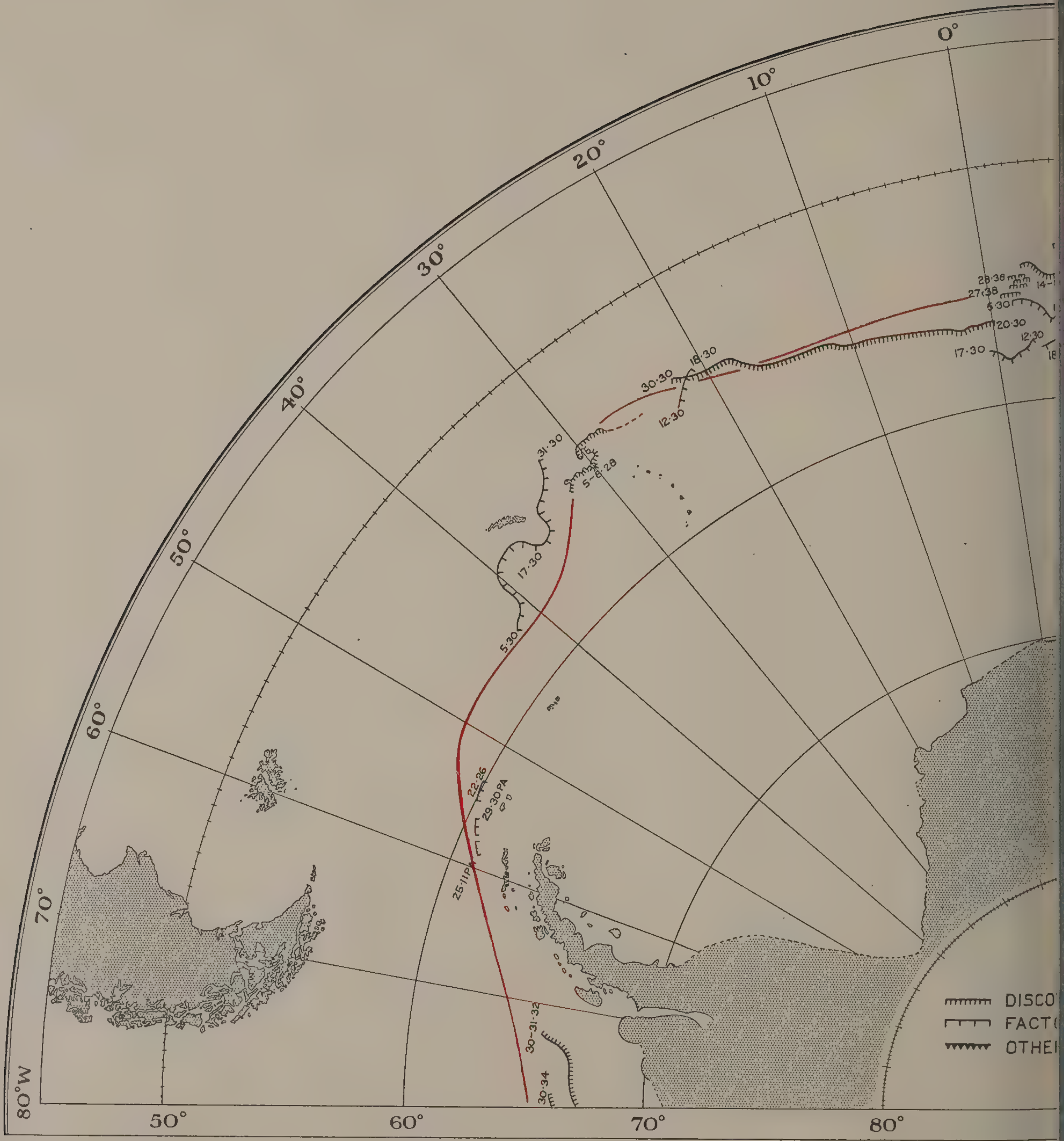

120°
130°
140°
150°
160°
170°
180°
170°
160°E
50°
60°
70°
80°
NEW ZEALAND
Balleny Is.
ROSS SEA
8-10-32
DISC
FACT
OTHE

PLATE LXXIII

SEPTEMBER, C.
Pacific Sector.


100°
90°
80°
70°
60°
50°
40°
30°
W20°
Cape Horn
Falkland Is.
BELLINGSHAUSEN
SEA
South Shetland Is.
Bransfield Str.
GRAHAM LAND
12·34
27·34
6·34
30·34
South Orkney Is.
South Georgia
19·28
WEDDELL
SEA
South Sandwich Is.
EE'S SHIPS
S
80°
70°
60°
50°


0°
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20°
30°
40°
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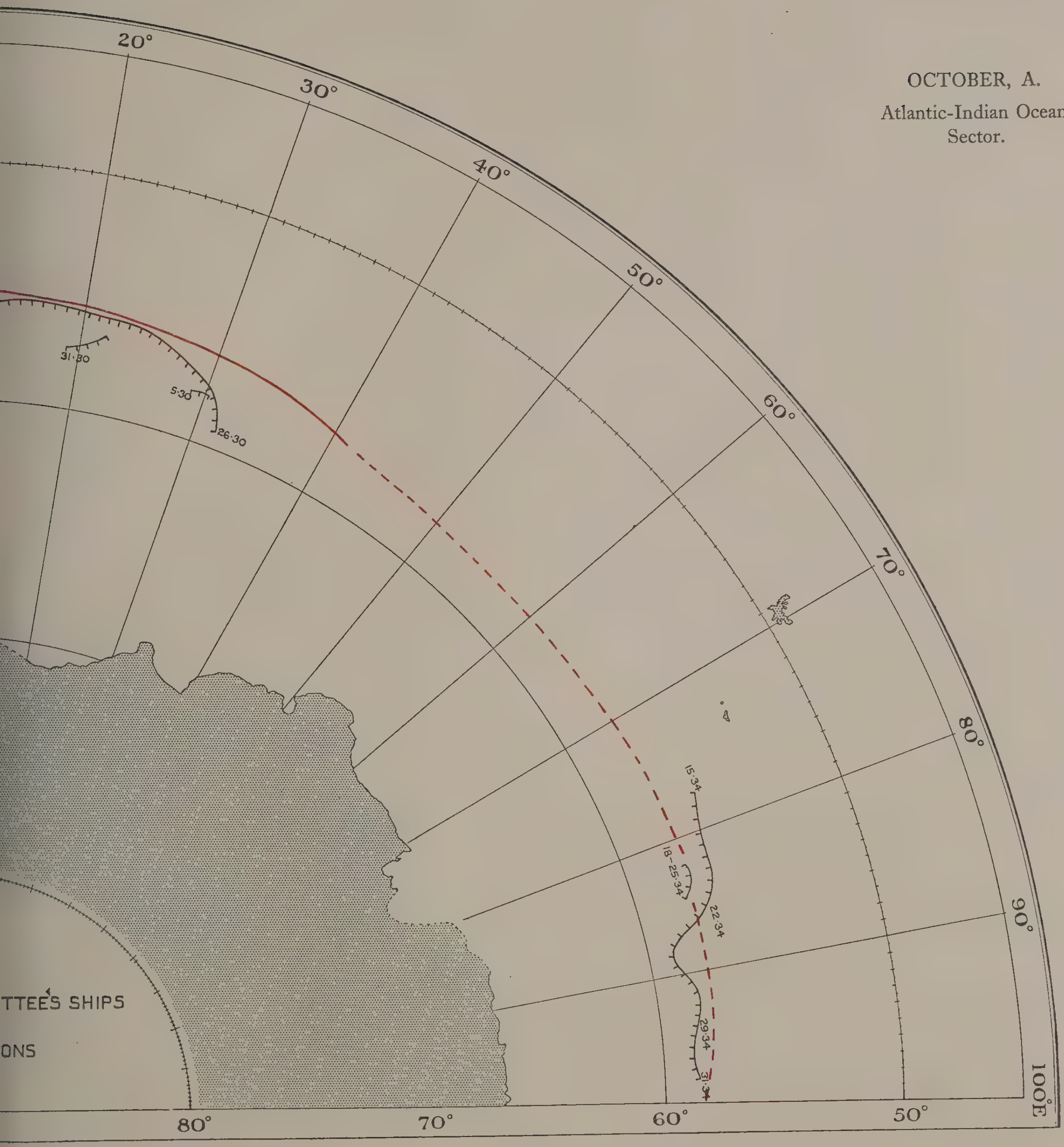
60°
70°
80°W
50°
60°
70°
80°
28·38
27·38
14-1
5·30
20·30
12·30
17·30
18
18·30
30·30
12·30
31·30
5-6·28
17·30
5·30
22·26
29·30 PA
25·11 PA
30-31·32
30·34
DISCO
FACT
OTHE

PLATE LXXIV

OCTOBER, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
31·30
5·30
26·30
15·34
18-25·34
22·34
29·34
31·34
TTEES SHIPS
ONS
80°
70°
60°
50°

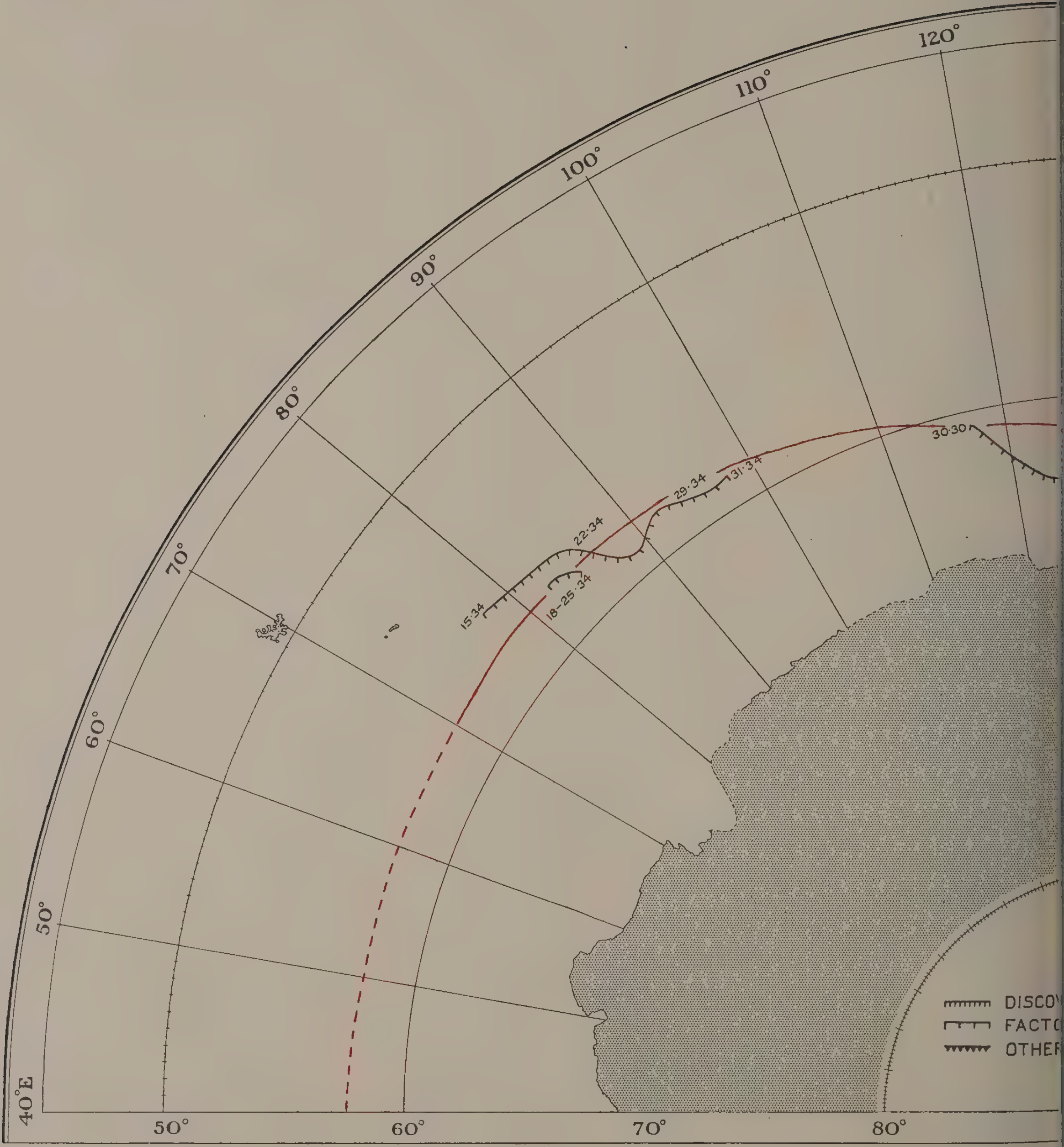
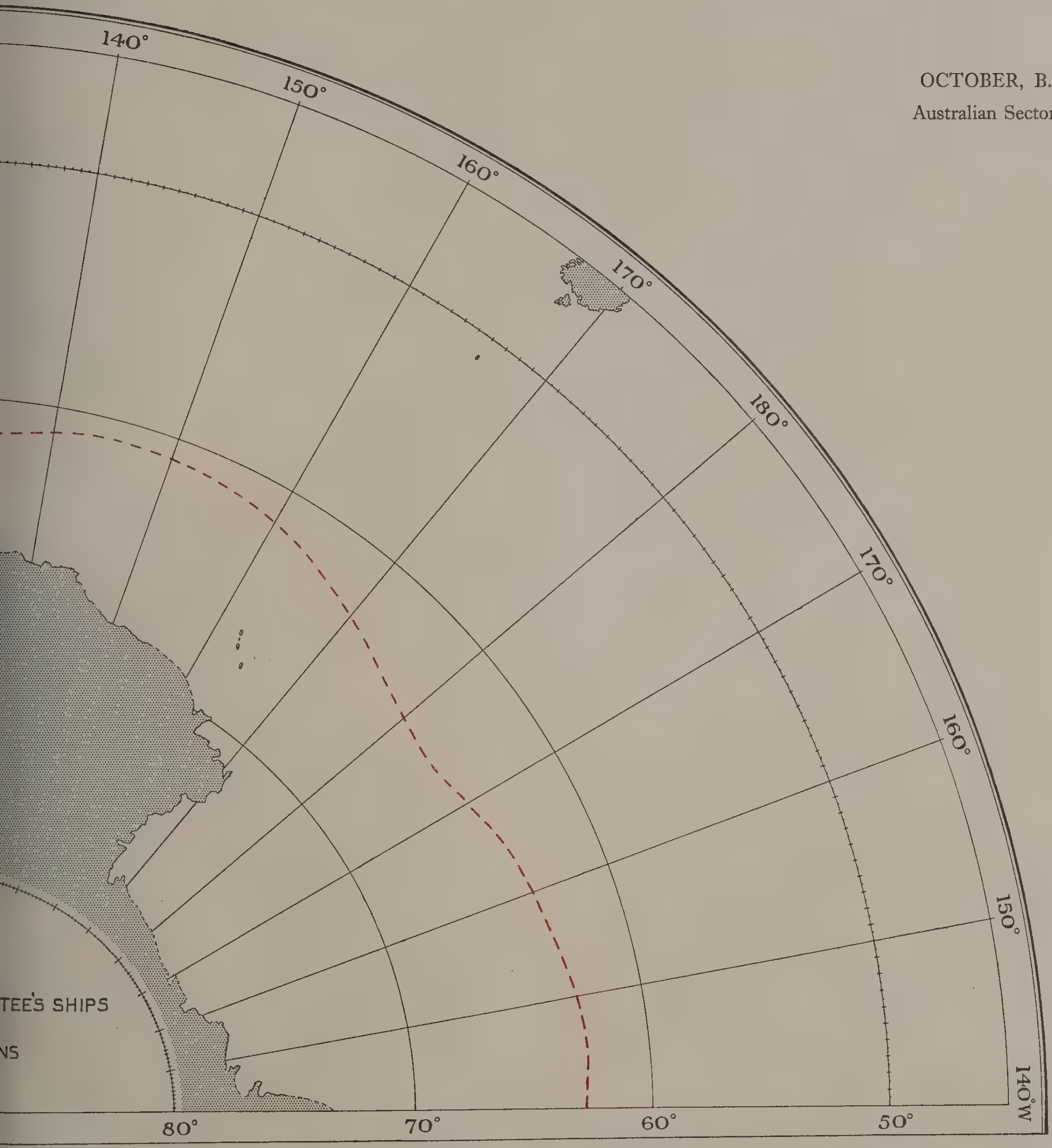

120°
110°
100°
90°
80°
70°
60°
50°
40°E
50°
60°
70°
80°
30·30
31·34
29·34
22·34
15·34
18–25·34
DISCOV
FACTO
OTHER

PLATE LXXV

OCTOBER, B.
Australian Sector.


140°
150°
160°
170°
180°
170°
160°
150°
140°W
80°
70°
60°
50°
TEE'S SHIPS
NS

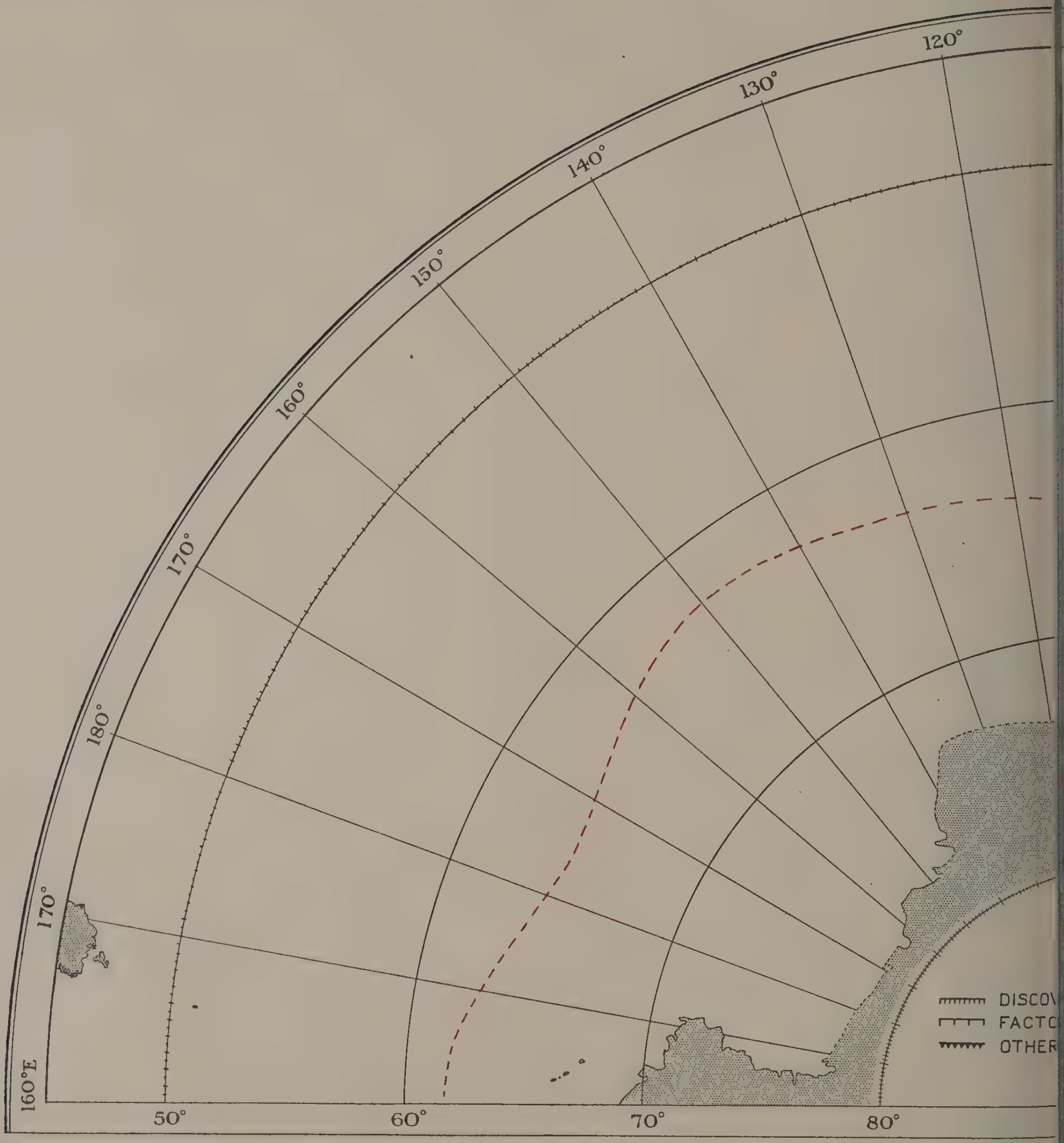
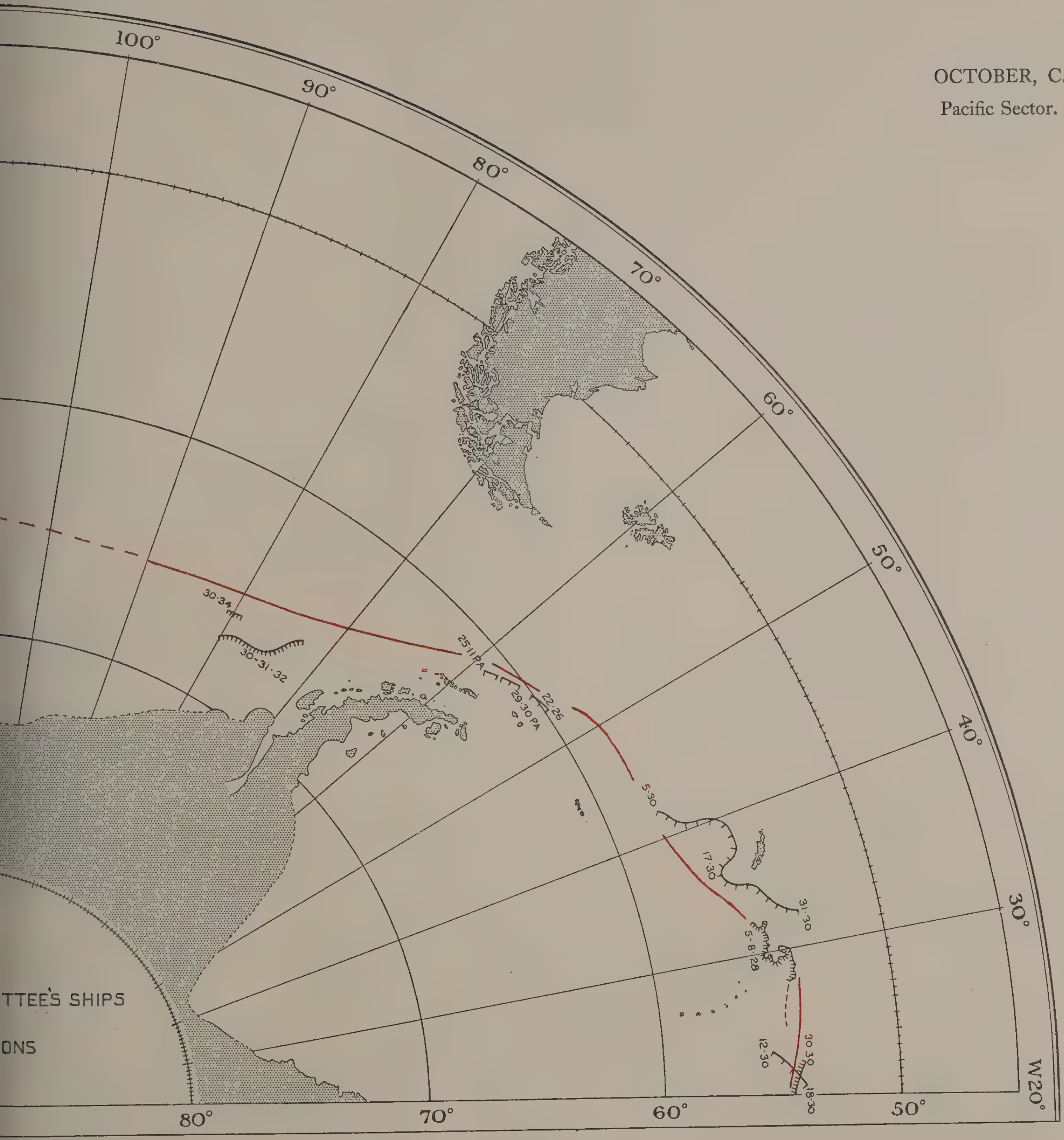
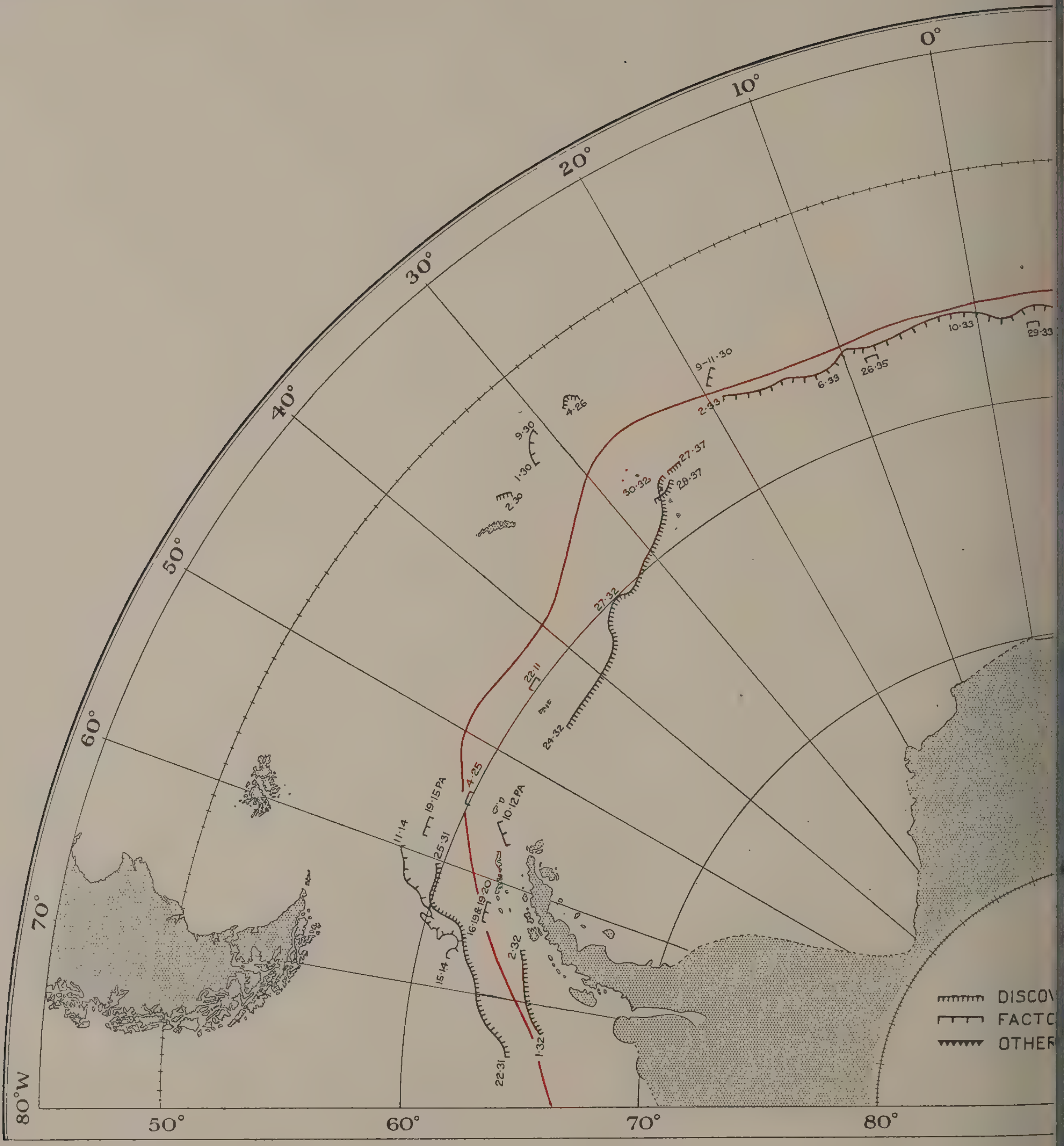

120°
130°
140°
150°
160°
170°
180°
170°
160°E
50°
60°
70°
80°
DISCOV
FACTO
OTHER

PLATE LXXVI

OCTOBER, C.

Pacific Sector.


100°
90°
80°
70°
60°
50°
40°
30°
W20°
30·34
30-31·32
25·11 PA
22·26
29·30 PA
5·30
17·30
31·30
5-8·28
12·30
30 30
18·30
TTEES SHIPS
ONS
80°
70°
60°
50°


0°
10°
20°
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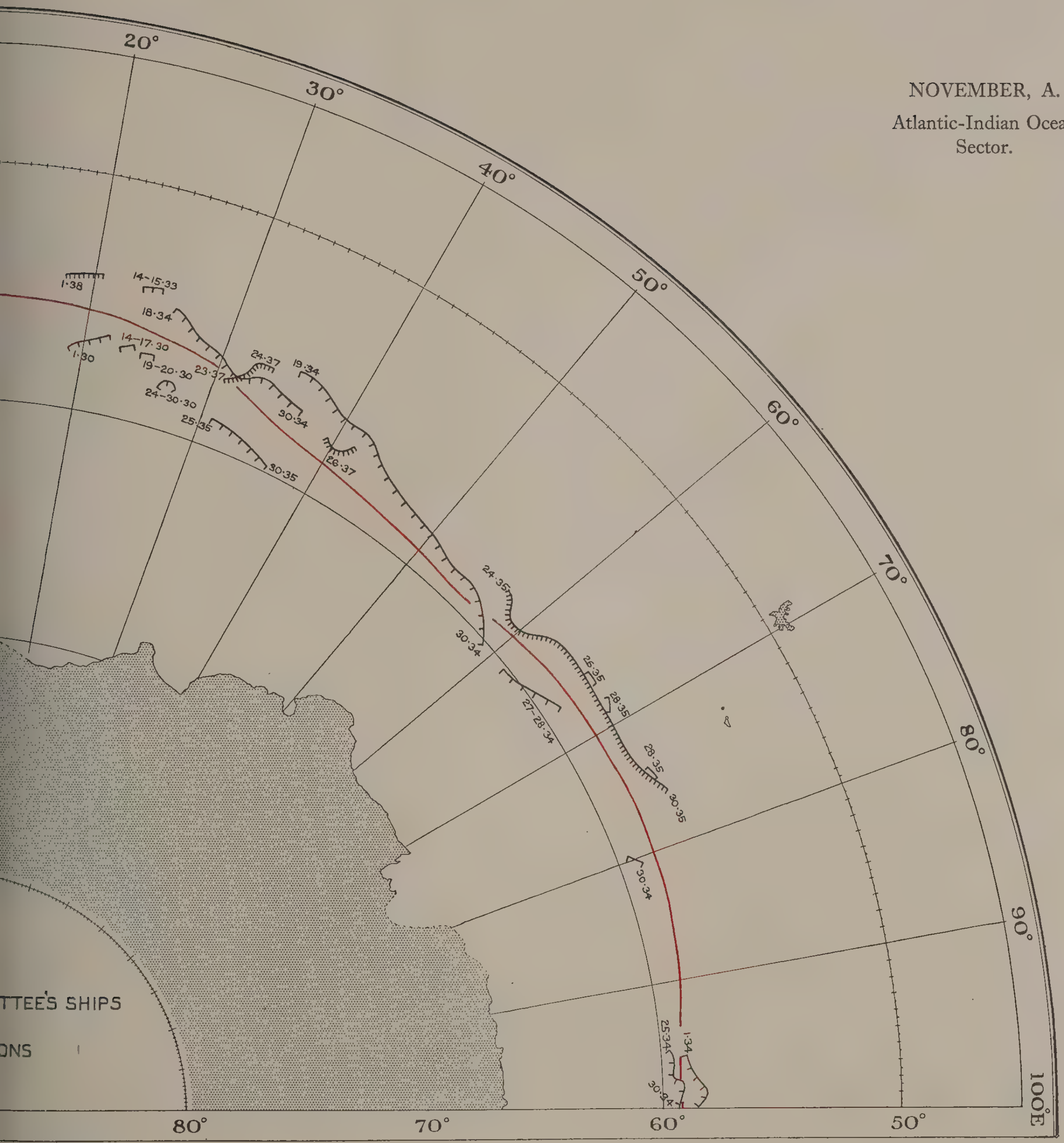
40°
50°
60°
70°
80°W
50°
60°
70°
80°
9-11·30
4·26
9·30
1·30
2·30
2·33
6·33
26·35
10·33
29·33
27·37
28·37
30·32
27·32
22·11
24·32
4·25
19·15 PA
10·12 PA
11·14
25·31
16·19 & 19·20
2·32
15·14
22·31
1·32
DISCOV
FACTC
OTHER

PLATE LXXVII

NOVEMBER, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
1·38
14–15·33
18·34
14–17·30
1·30
19–20·30
23·37
24·37
19·34
24–30·30
30·34
25·35
28·37
30·35
24·35
30·34
25·35
28·35
27·28·34
28·35
30·35
30·34
25·34
1·34
30·34
TTEE'S SHIPS
ONS
80°
70°
60°
50°

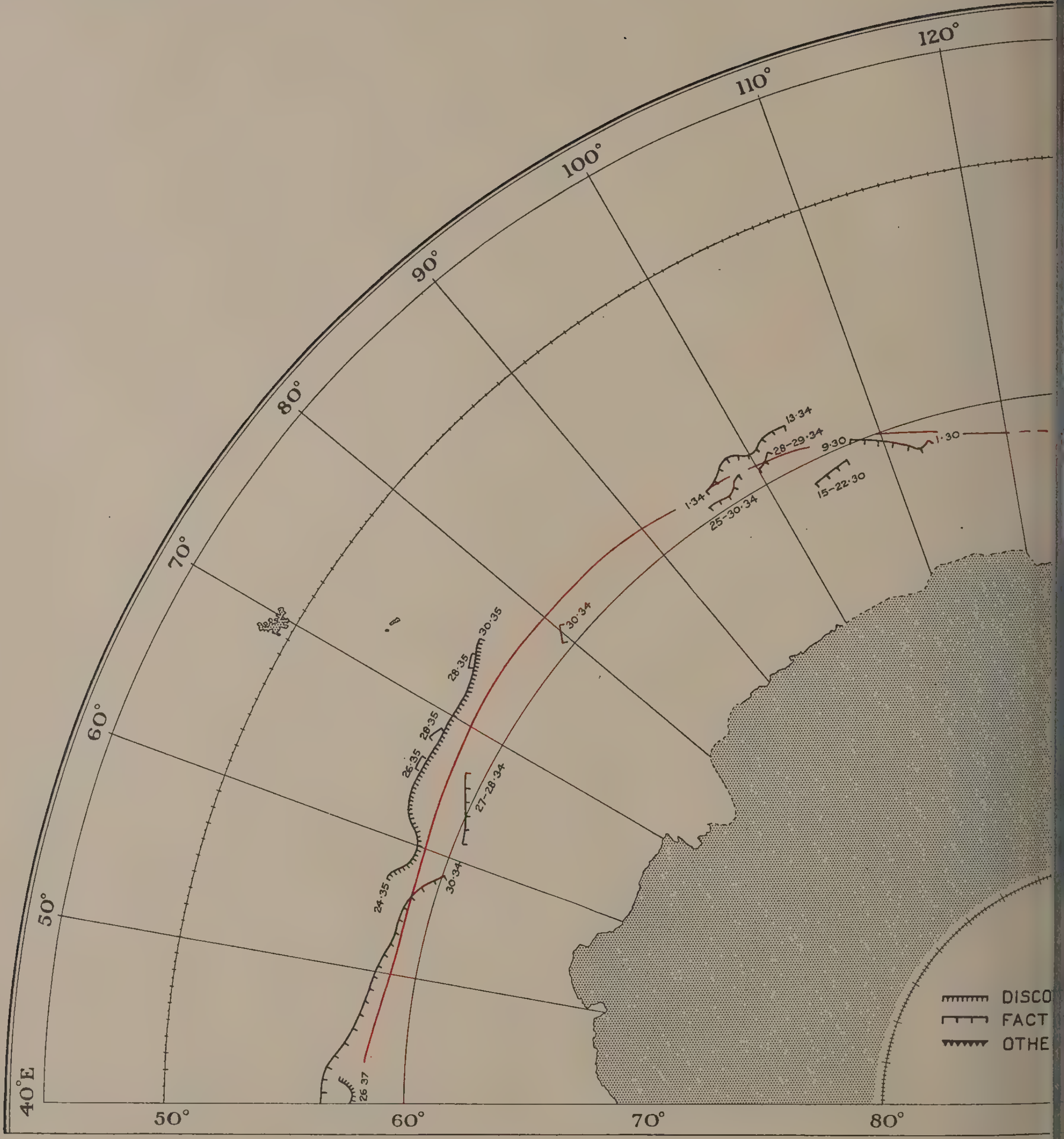
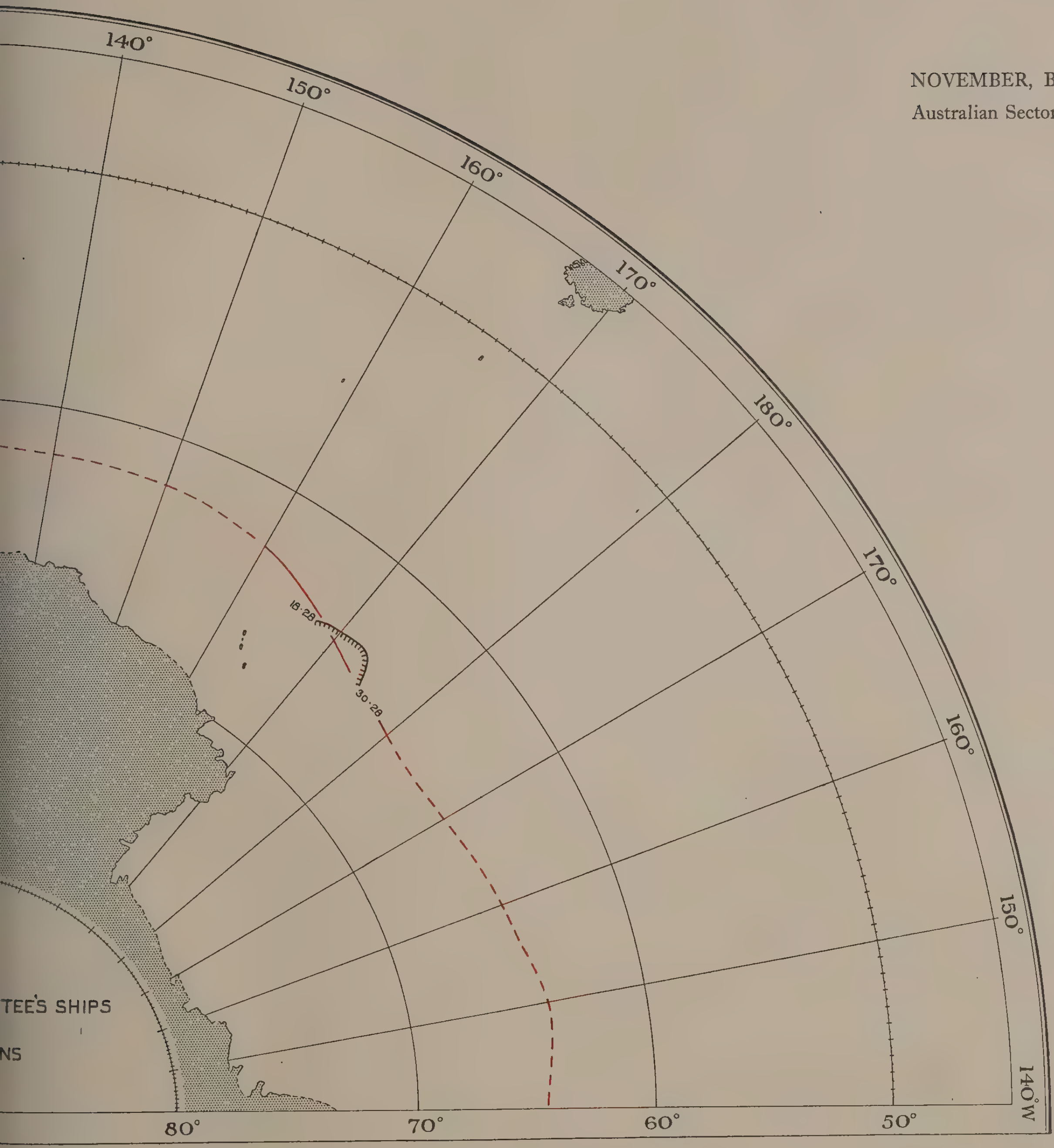
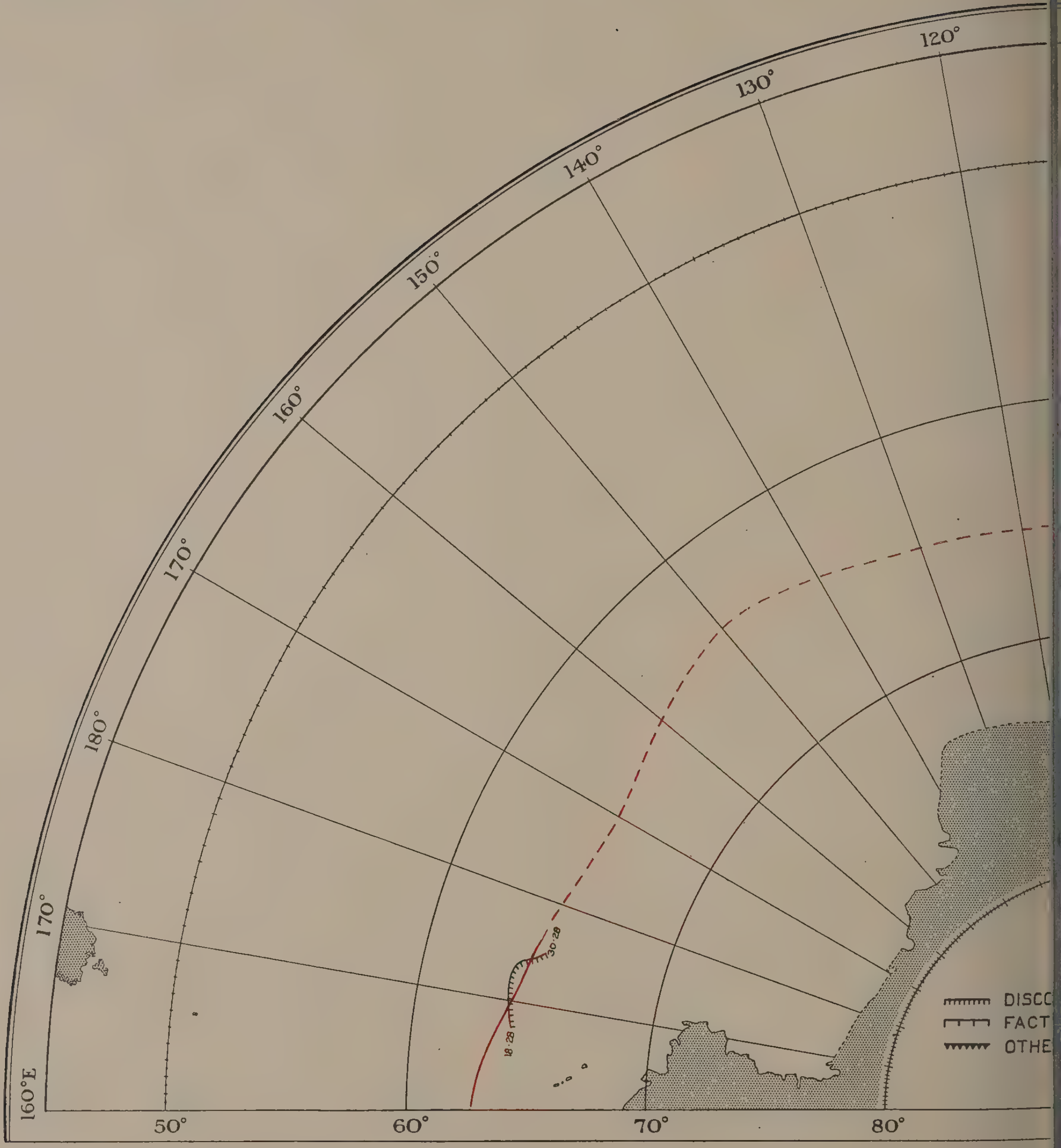

120°
110°
100°
90°
80°
70°
60°
50°
40°E
50°
60°
70°
80°
13·34
28–29·34
9·30
1·30
1·34
25–30·34
15–22·30
30·34
30·35
28·35
28·35
26·35
27–28·34
24·35
30·34
26 37
DISCO
FACT
OTHE

PLATE LXXVIII

NOVEMBER, B.
Australian Sector.


140°
150°
160°
170°
180°
170°
160°
150°
140°W
80°
70°
60°
50°
18·28
30·28
TEE'S SHIPS
NS


120°
130°
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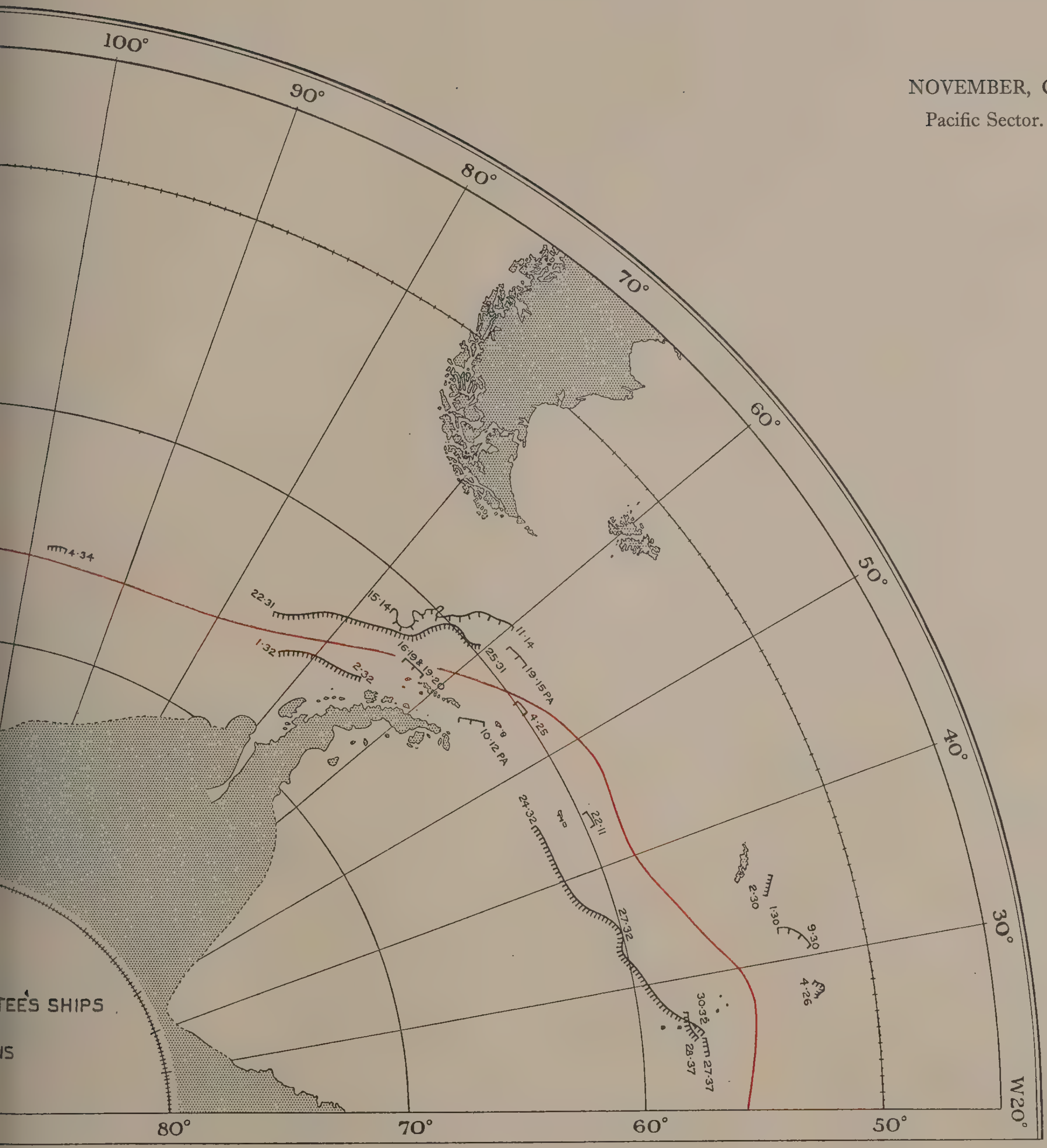
180°
170°
160°E
50°
60°
70°
80°
30·28
18·28
DISCO
FACT
OTHE

PLATE LXXIX

NOVEMBER, C.
Pacific Sector.


100°
90°
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70°
60°
50°
40°
30°
W20°
80°
70°
60°
50°
4·34
22·31
15·14
11·14
1·32
2·32
16·19 & 19·20
25·31
19·15 PA
4·25
10·12 PA
24·32
22·11
27·32
2·30
1·30
9·30
4·26
30·32
28·37
27·37
TEES SHIPS
S

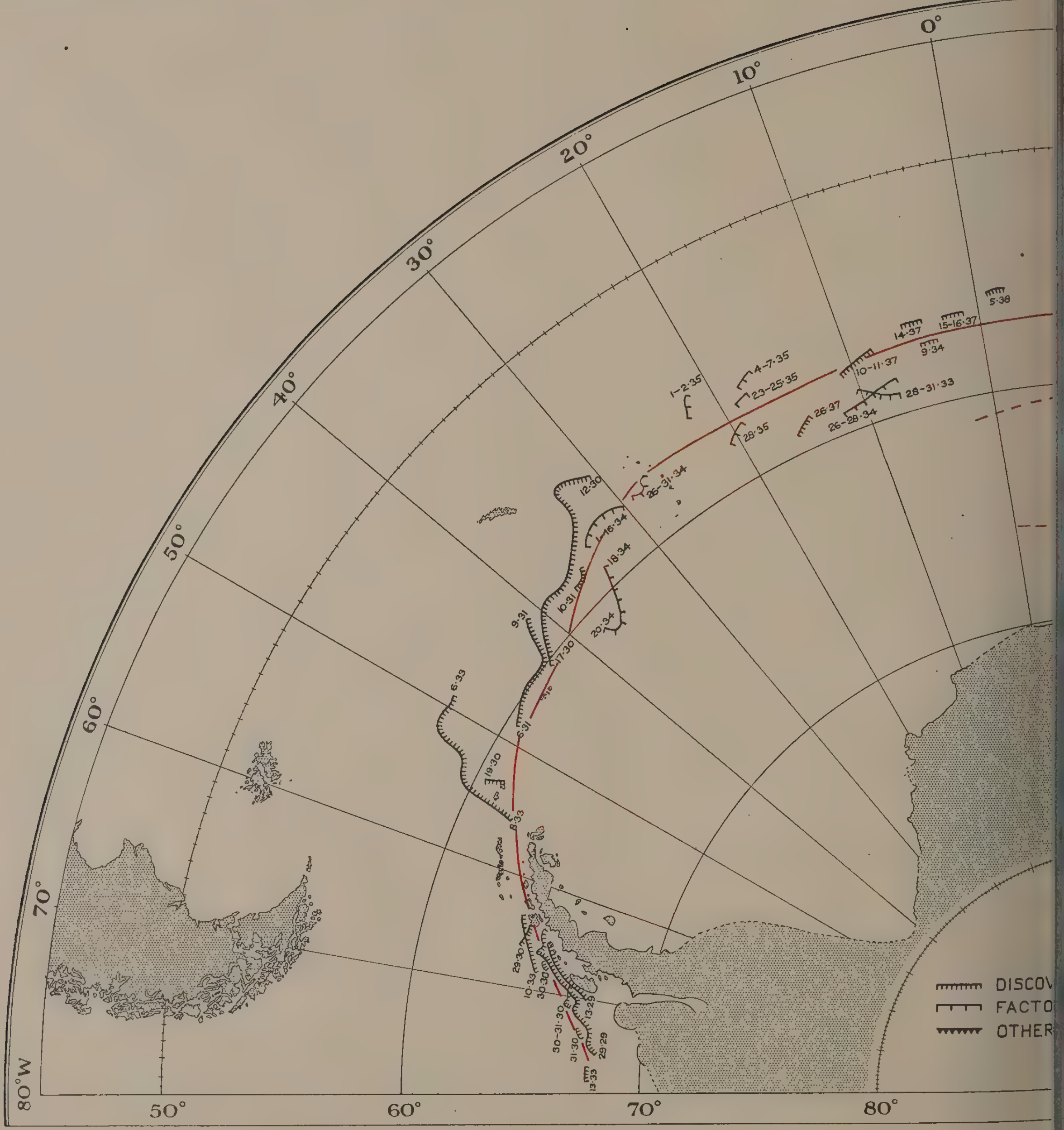
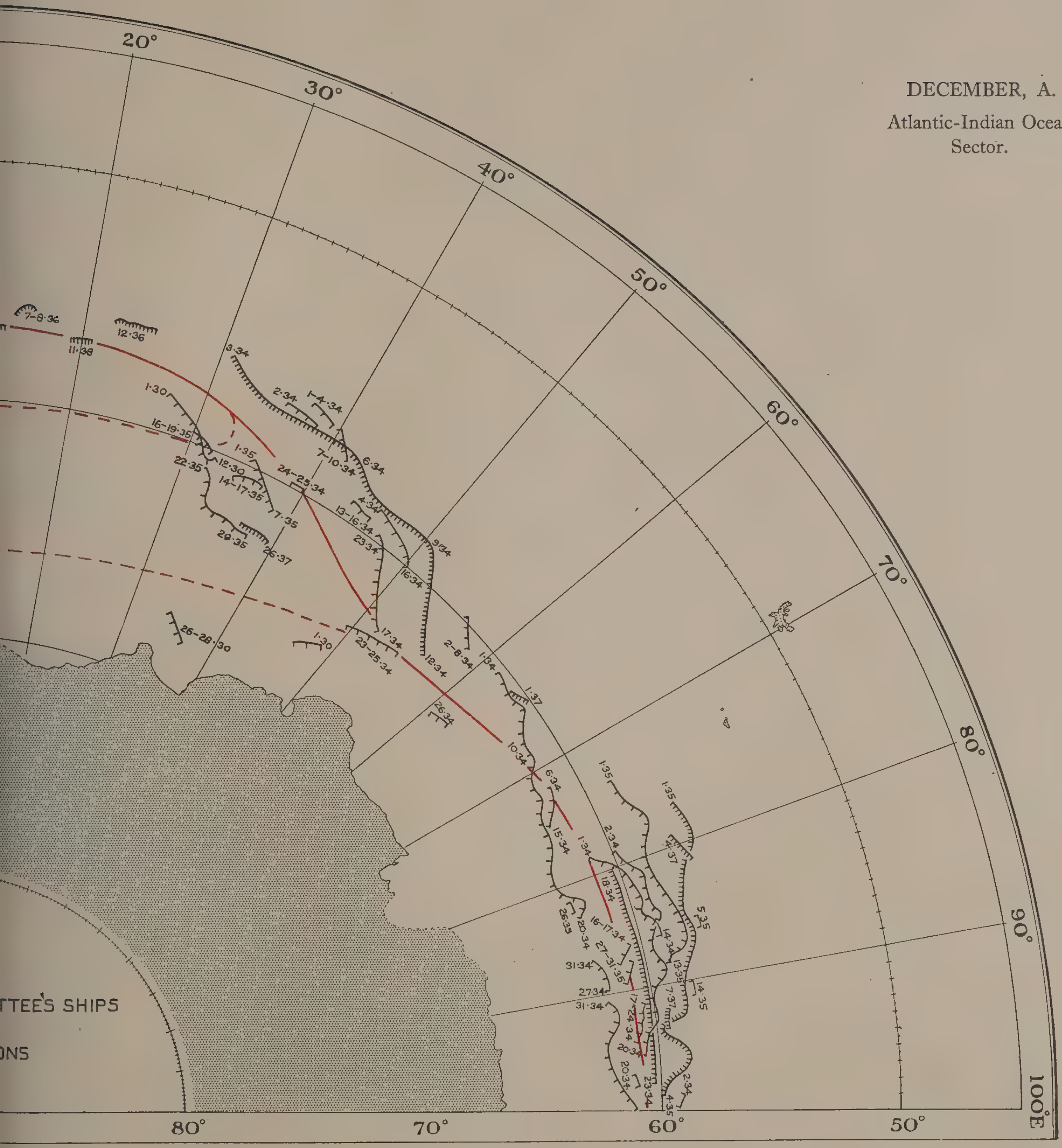

0°
10°
20°
30°
40°
50°
60°
70°
80°W
50°
60°
70°
80°
5·38
14·37
15-16·37
9·34
10-11·37
28-31·33
26·37
26-28·34
1-2·35
4-7·35
23-25·35
28·35
26-31·34
12·30
1-16·34
18·34
10·31
20·34
9·31
17·30
6·33
6·31
19·30
8·33
29·30
10·33
30·30
13·29
30-31·30
31·30
29·29
13·33
DISCOV
FACTO
OTHER

PLATE LXXX

DECEMBER, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
80°
70°
60°
50°
7-8·36
12·36
11·36
3·34
2·34
1-4·34
1·30
16-19·35
1·35
6·34
7-10·34
22·35
12·30
14-17·35
24-25·34
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13-16·34
7·35
29·35
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1·30
17·34
23-25·34
12·34
2-8·34
1·34
1·37
26·34
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6·34
1·35
1·35
15·34
1·34
2·34
4·37
18·34
26·35
20·34
16-17·34
27-31·35
14·34
13·35
5·35
31·34
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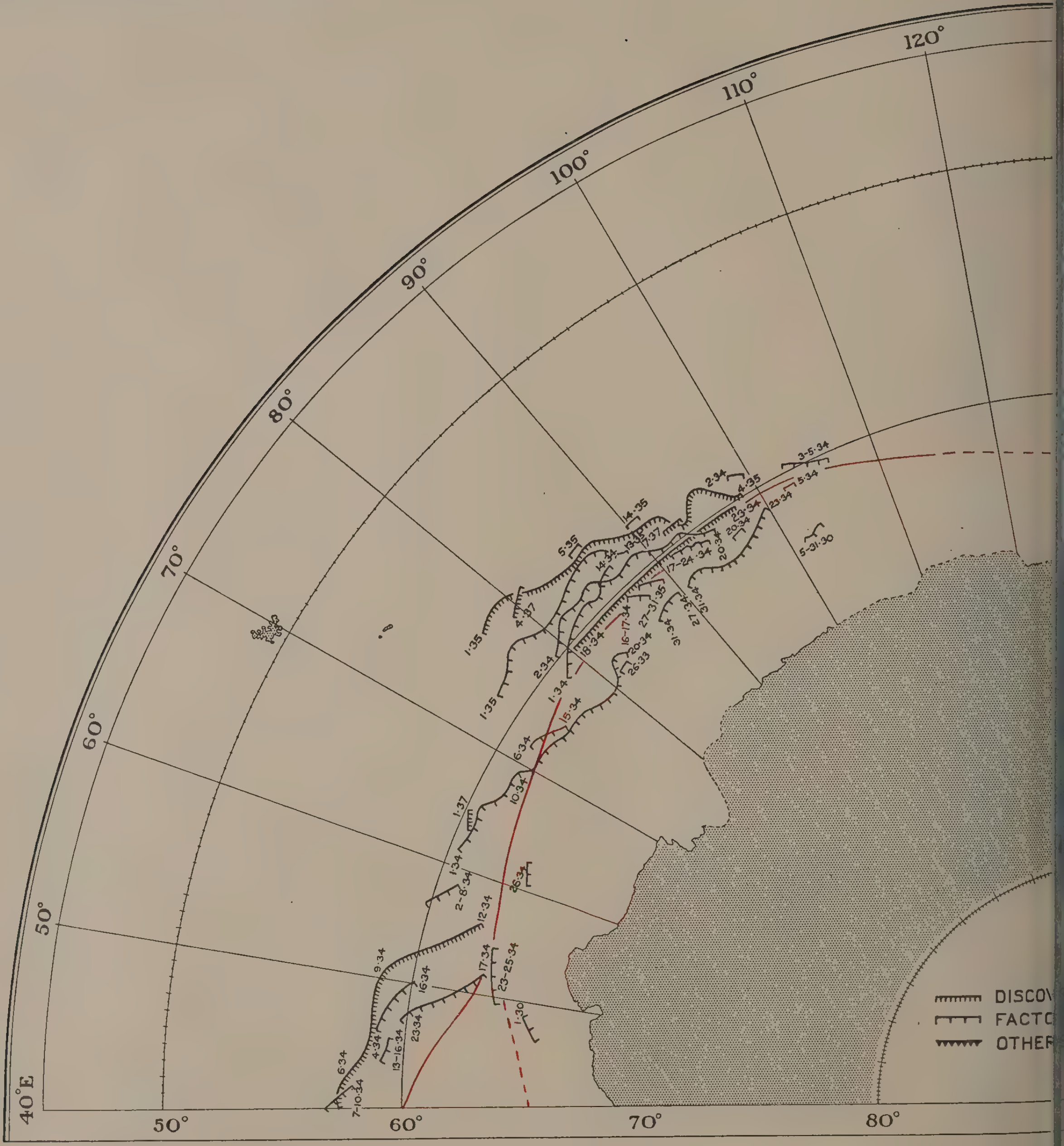
4·35
TTEE'S SHIPS
ONS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4·35
23·34
20·34
23·34
14·35
5-31·30
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7·37
13·35
14·34
17-24·34
20·34
27·31·35
31·34
27·34
31·34
4·37
1·35
18·34
16-17·34
20·34
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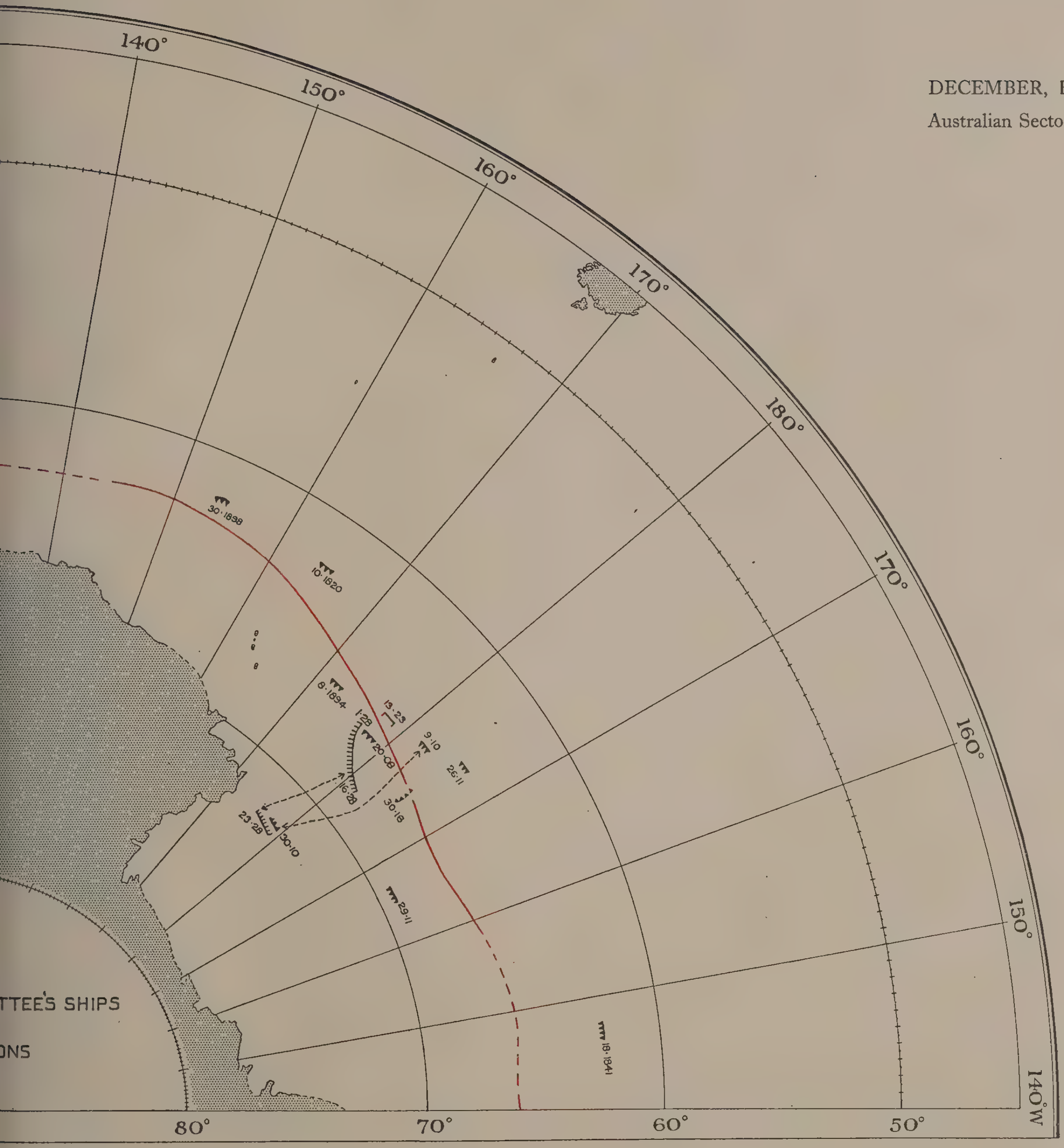
31·34
2·34
1·35
1·34
15·34
6·34
10·34
1·37
1·34
26·34
2-8·34
12·34
9·34
16·34
17·34
23-25·34
23·34
4·34
13-16·34
6·34
7-10·34
1·30
DISCOV
FACTO
OTHER

PLATE LXXXI

DECEMBER, B.
Australian Sector.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80°
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60°
50°
30·1898
10·1820
8·1894
13·23
1·28
20·08
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26·11
16·28
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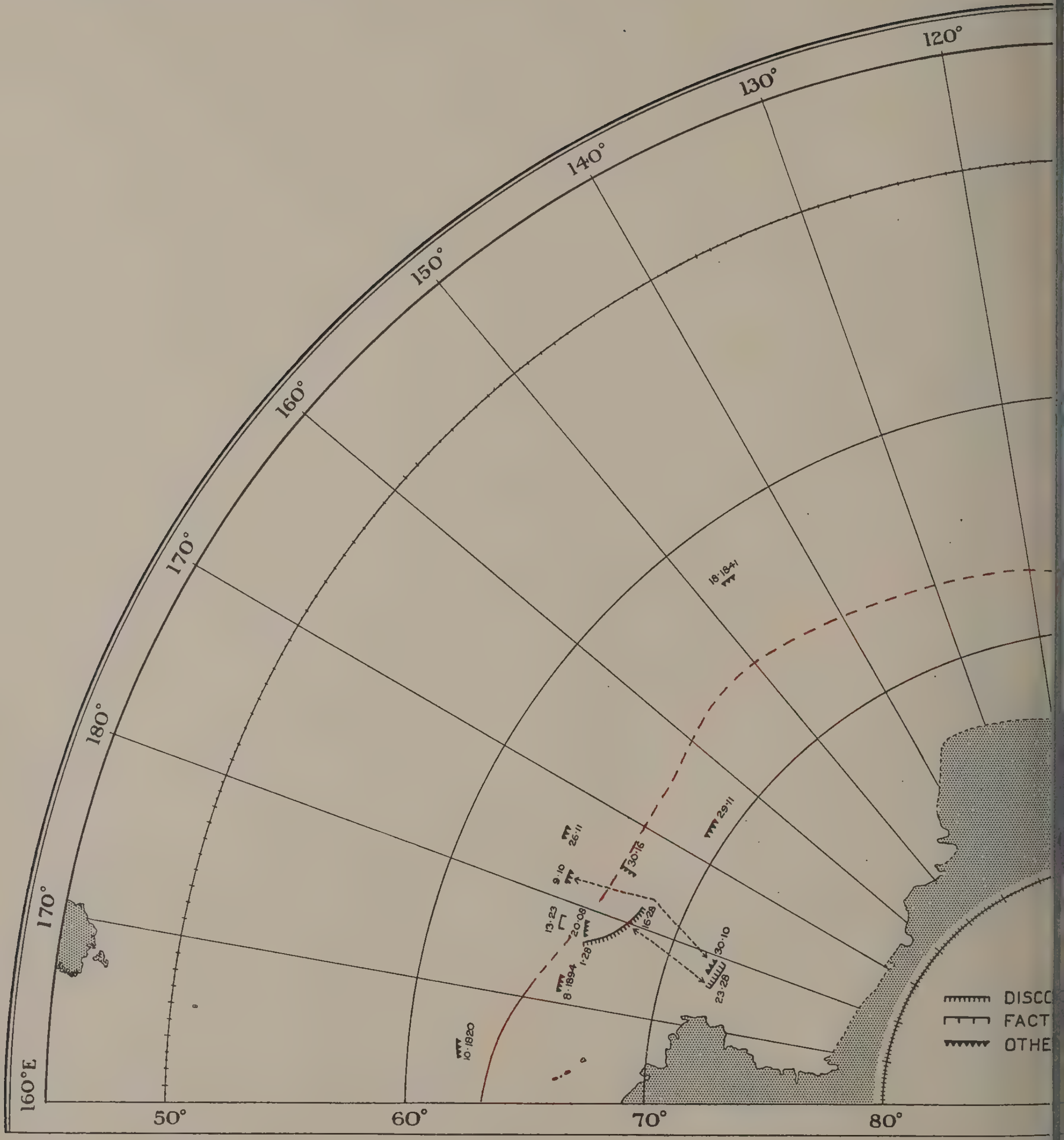
23·28
30·10
29·11
18·1841
TTEE'S SHIPS
ONS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80°
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26·11
30·16
9·10
13·23
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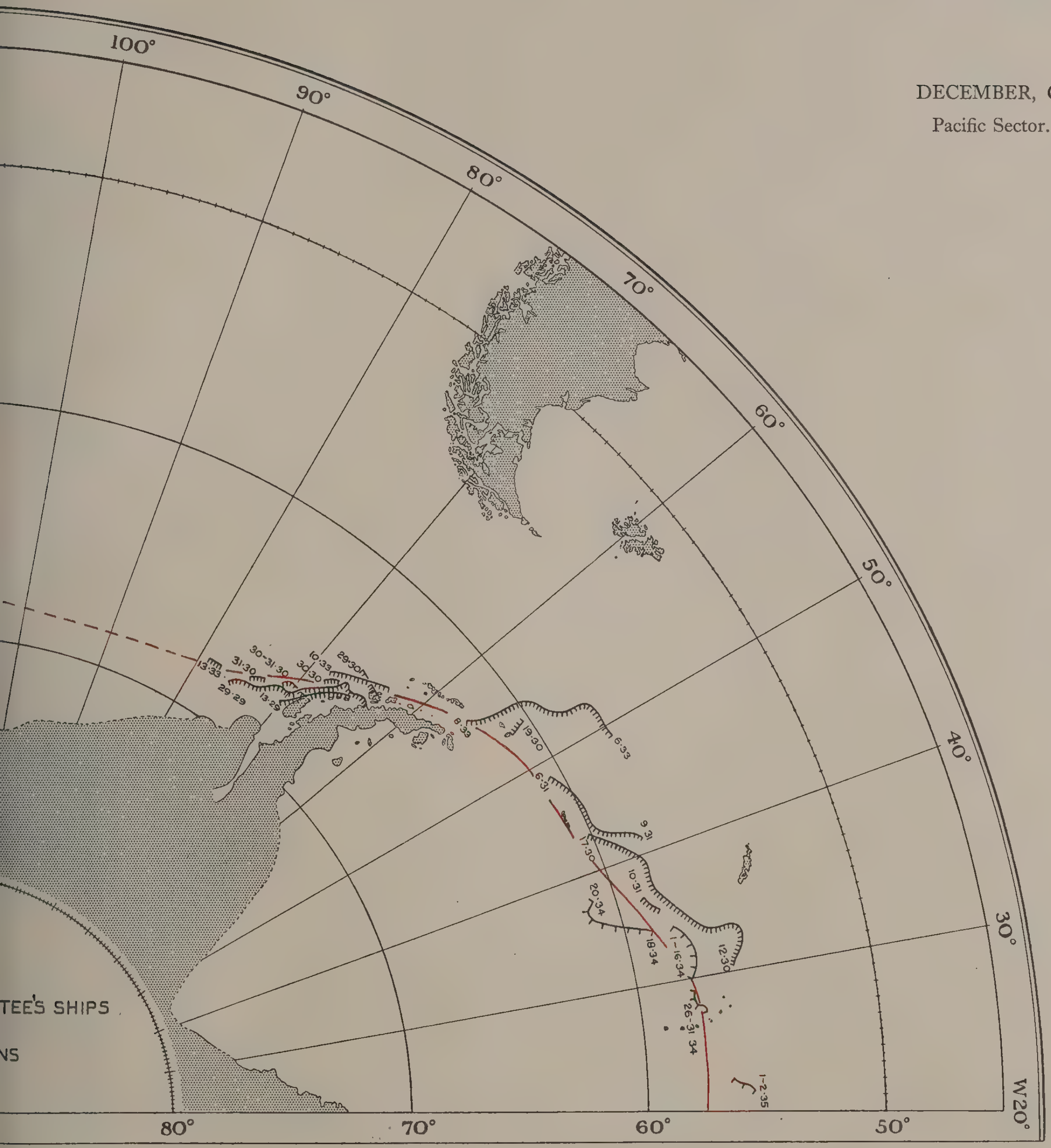
23·28
8·1894
10·1820
DISC
FACT
OTHE

DECEMBER, C.
Pacific Sector.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80°
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50°
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29·29
13·29
30·30
10·33
29·30
8·33
19·30
6·33
6·31
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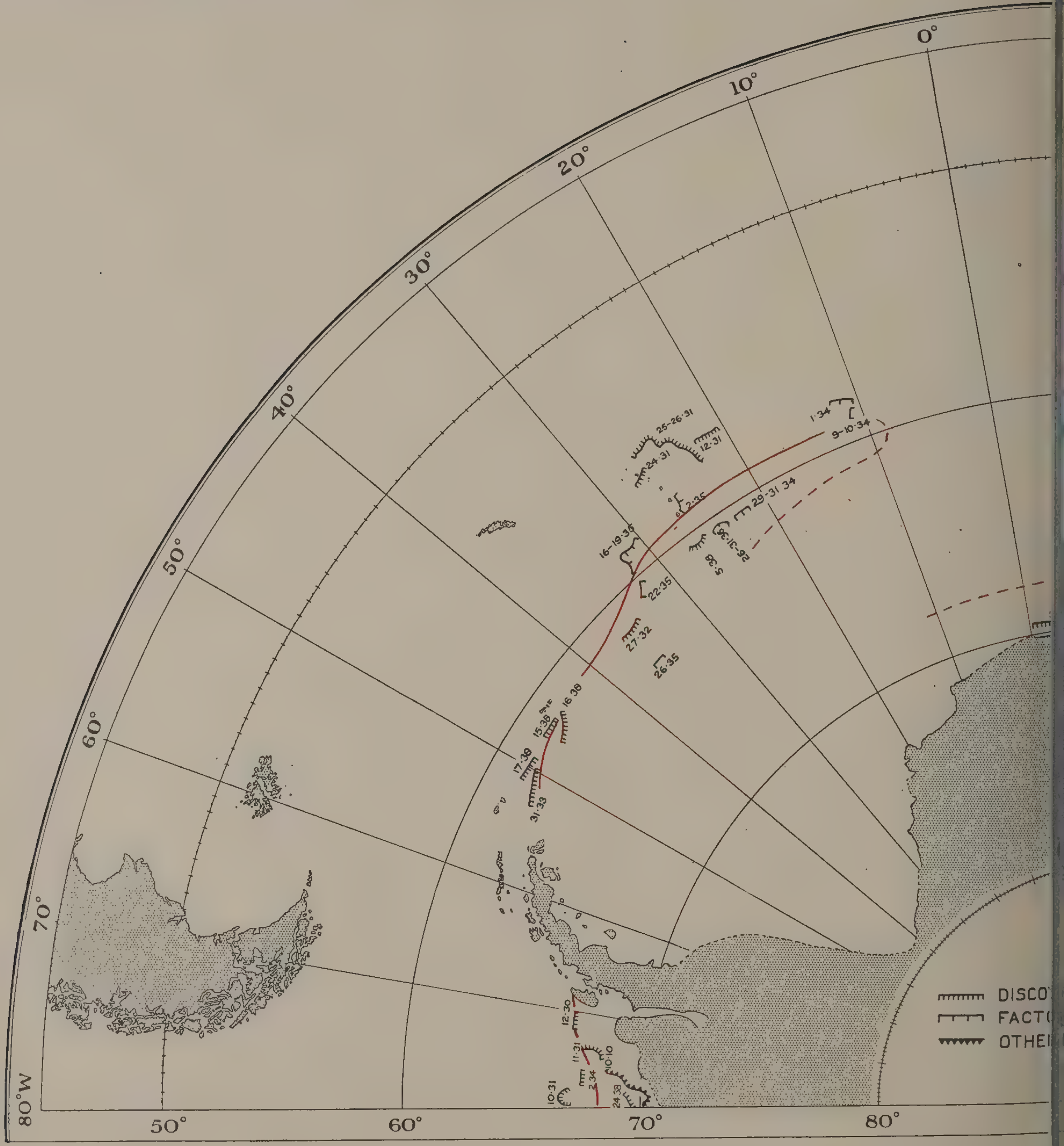
20·34
18·34
1-16·34
12·30
26-31 34
1-2·35
TEE'S SHIPS
NS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70°
80°
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9-10·34
25-26·31
12·31
24·31
2·35
29-31 34
16-19·35
26-31·36
5·38
22·35
27·32
26·35
16 38
15·38
17·38
31·33
12·30
11·31
10·10
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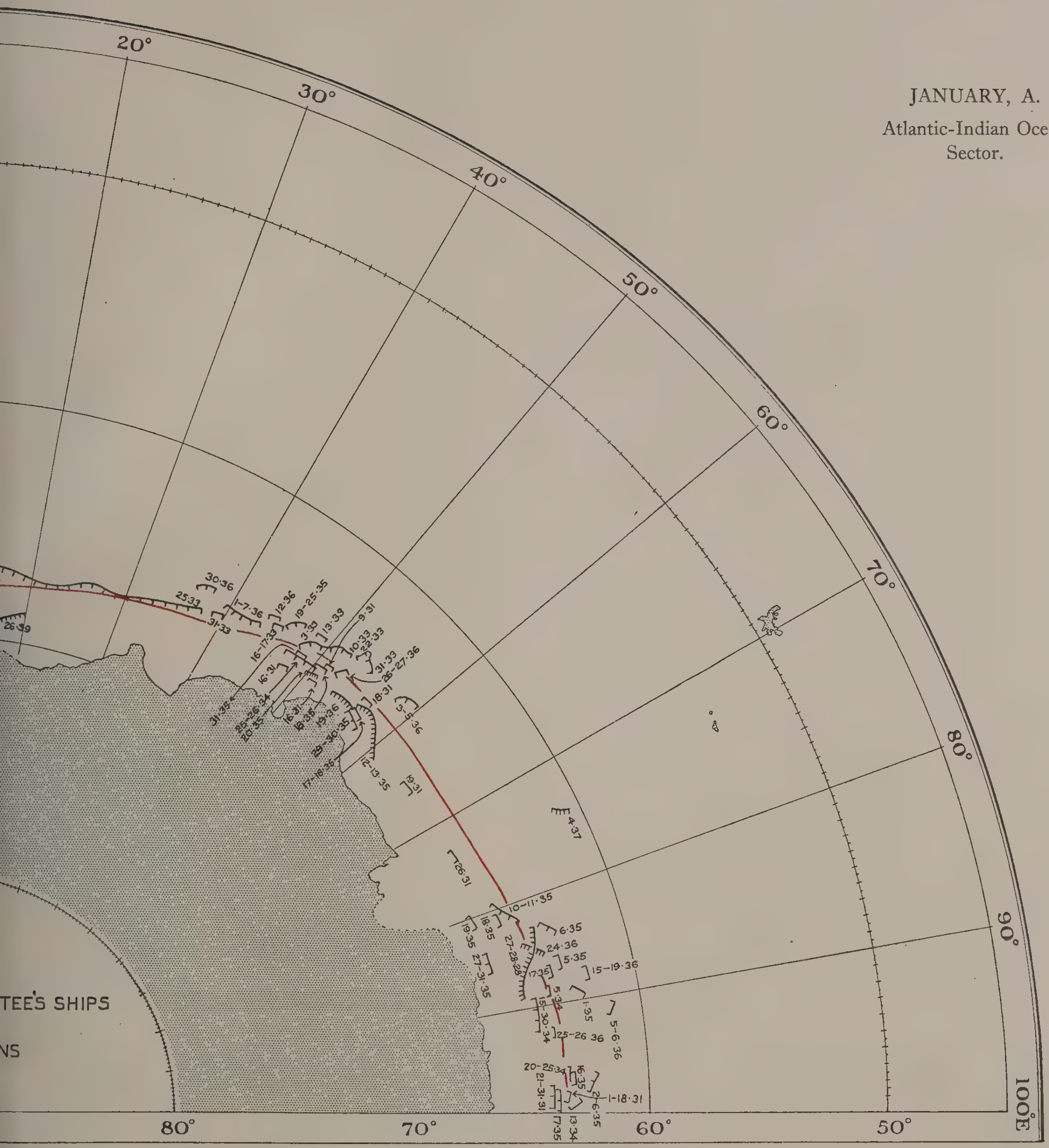
10·31
24 38
DISCO
FACT
OTHE

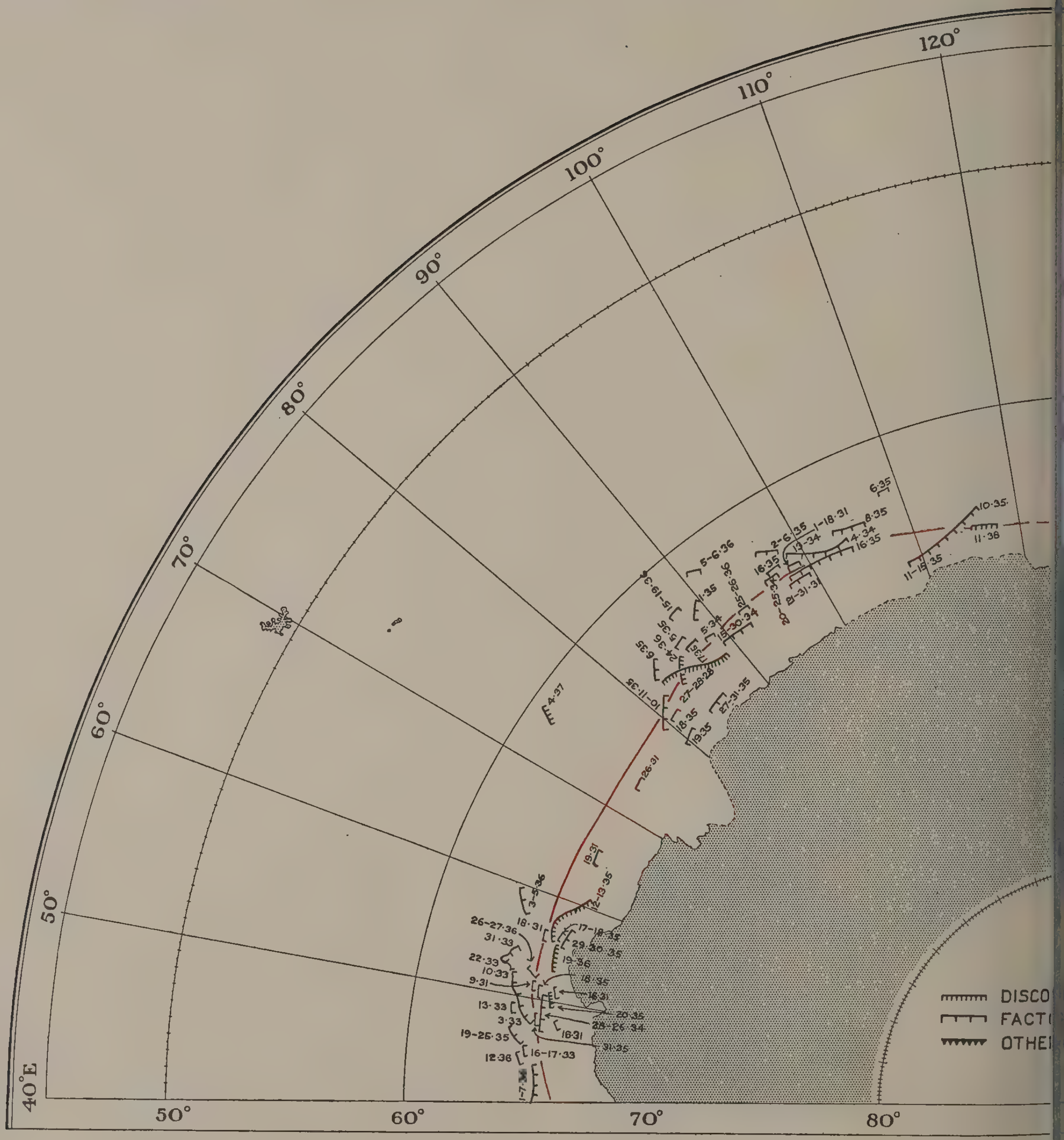
PLATE LXXXIII

JANUARY, A.

Atlantic-Indian Ocean
Sector.



20°
30°
40°
50°
60°
70°
80°
90°
100°E
80°
70°
60°
50°
TEE'S SHIPS
NS
26·39
30·36
25·33
31·33
1–7·36
12·36
19–25·35
16–17·33
3·33
13·33
9·31
10·33
22·33
31·33
25–27·36
16·31
18·31
31·35
25–26·34
20·35
16·31
16·35
19·36
29–30·35
3–5·36
17–18·36
12–13·35
15·31
4·37
26·31
10–11·35
19·35
18·35
27–28·28
27–31·35
6·35
24·36
5·35
17·35
15–19·36
5·34
15–30·34
1·35
5–6·36
25–26 36
20–25·34
21–31·31
16·35
2–6·35
1–18·31
17·35
13·34


120°
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40°E
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80°
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4·34
16·35
11·36
11–15·35
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5–6·36
25–26·36
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15–19·3
1·35
5·34
30·34
5·36
24·36
16·35
27–28·28
27–31·35
10–11·35
18·35
19·35
4·37
12·6·31
19·31
12–13·35
3–5·36
18·31
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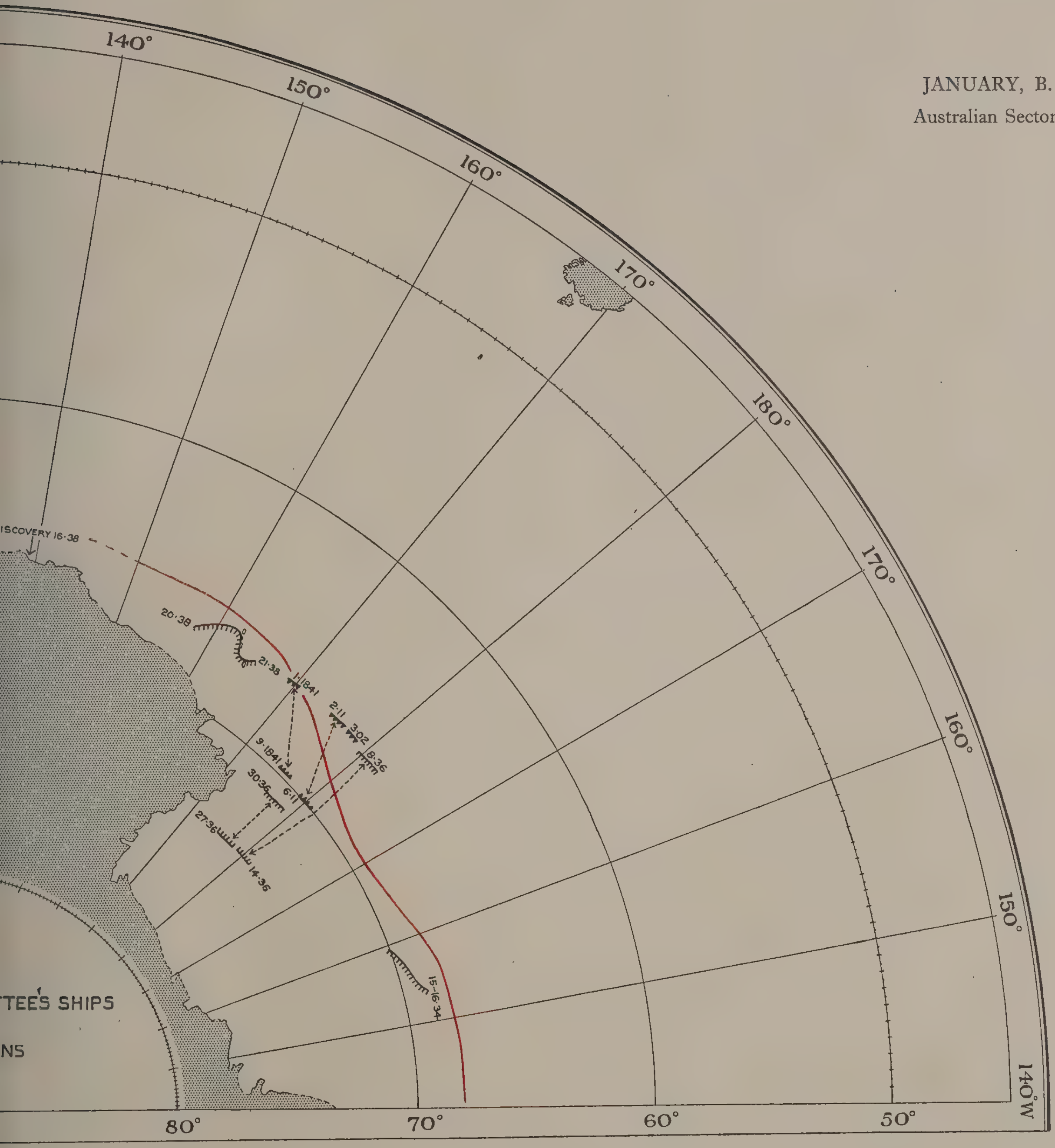
26–27·36
31·33
29·30·35
19·36
22·33
10·33
9·31
18·35
16·31
13·33
20·35
3·33
23–25·34
19–25·35
16·31
31·35
12·36
16–17·33
1–7·36
DISCO
FACT
OTHE

PLATE LXXXIV

JANUARY, B.

Australian Sector.


140°
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180°
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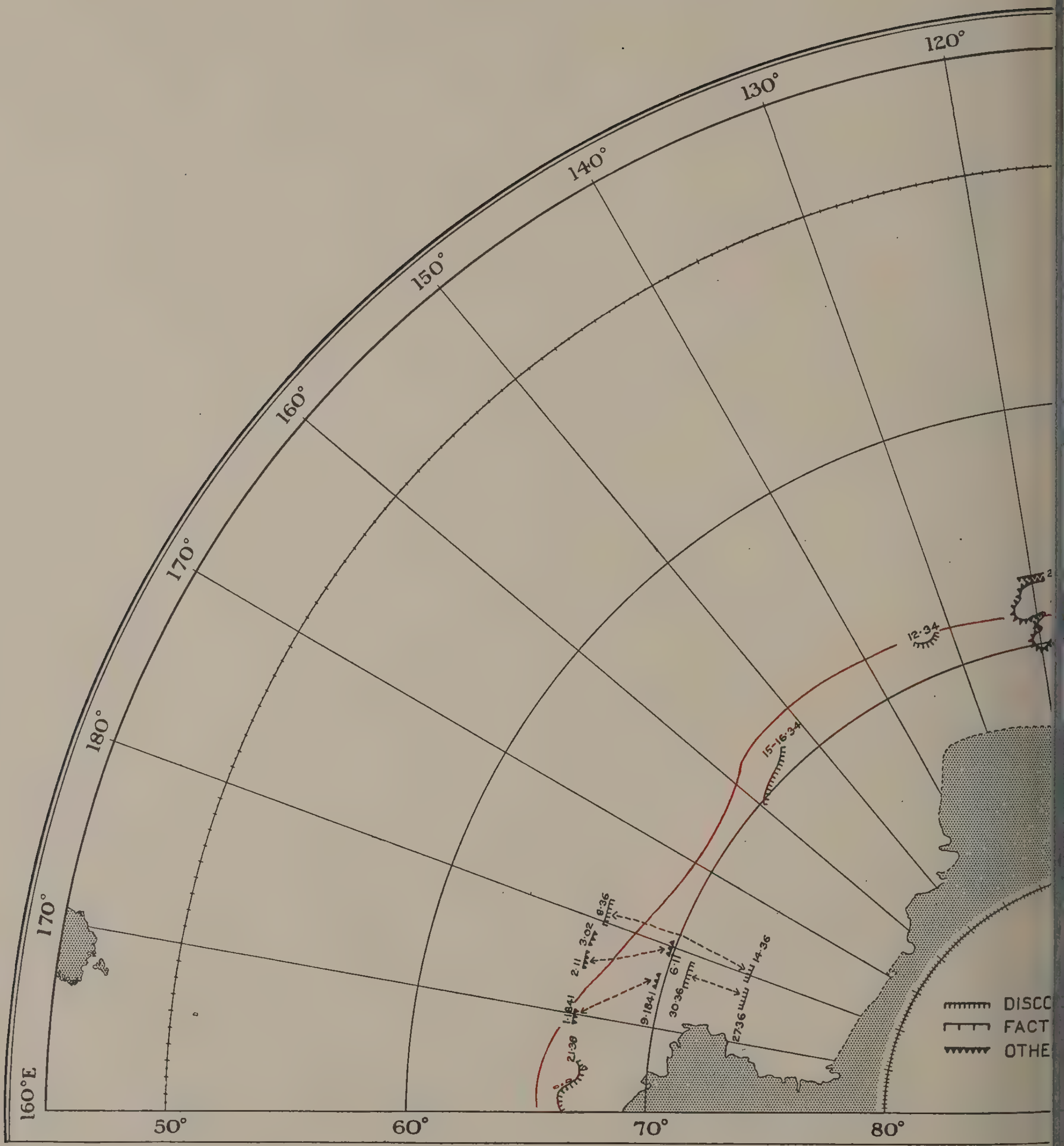
160°
150°
140°W
80°
70°
60°
50°
ISCOVERY 16·38
20·38
21·38
1·1841
2·11
3·02
8·36
9·1841
30·36
6·11
27·36
14·36
15-16·34
TEES SHIPS
NS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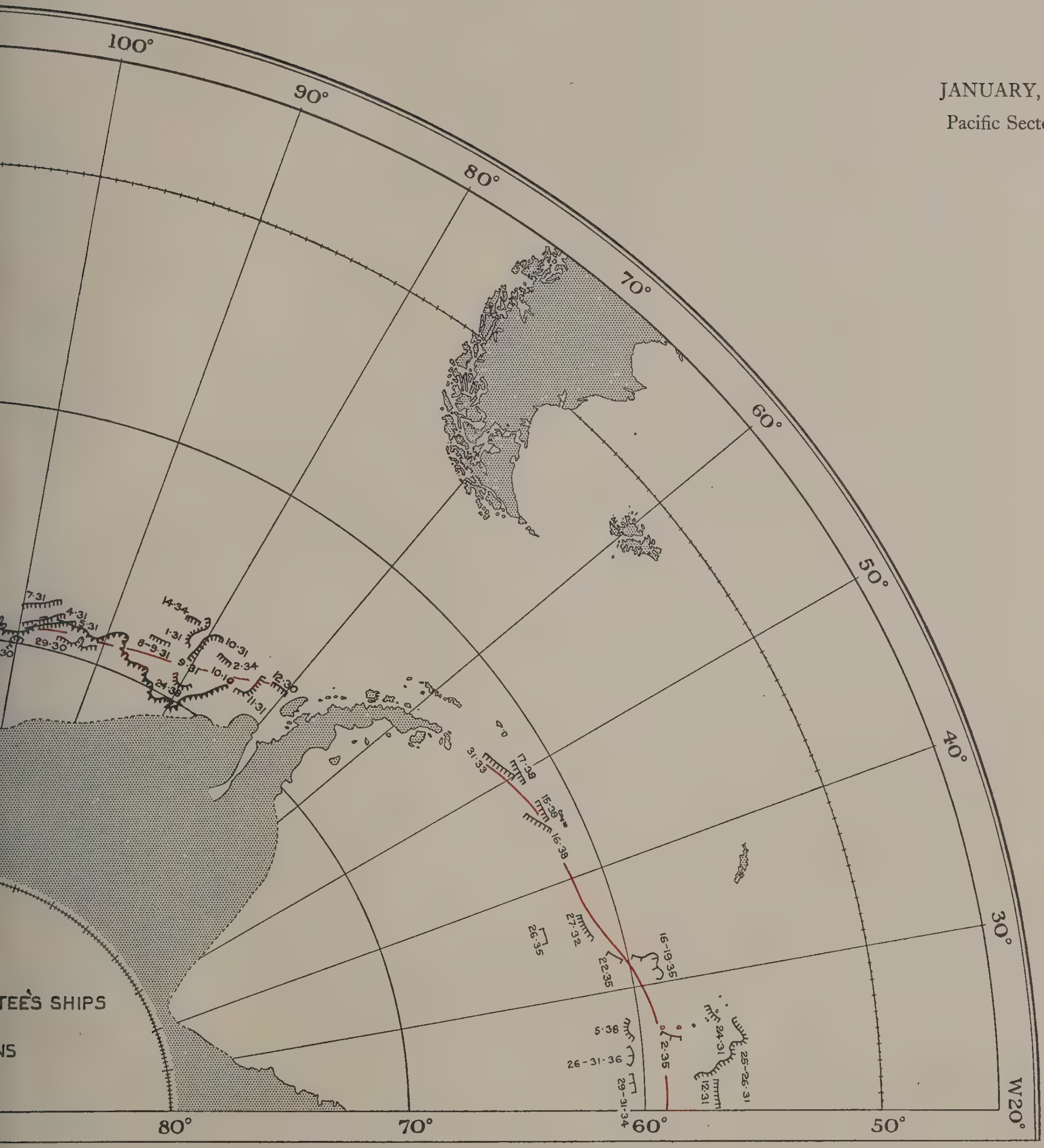
50°
60°
70°
80°
12·34
15-16·34
8·36
3·02
2·11
6·11
14·36
1·1841
9·1841
30·36
27·36
21·38
DISC
FACT
OTHE

PLATE LXXXV

JANUARY, C.
Pacific Sector.


100°
90°
80°
70°
60°
50°
40°
30°
W20°
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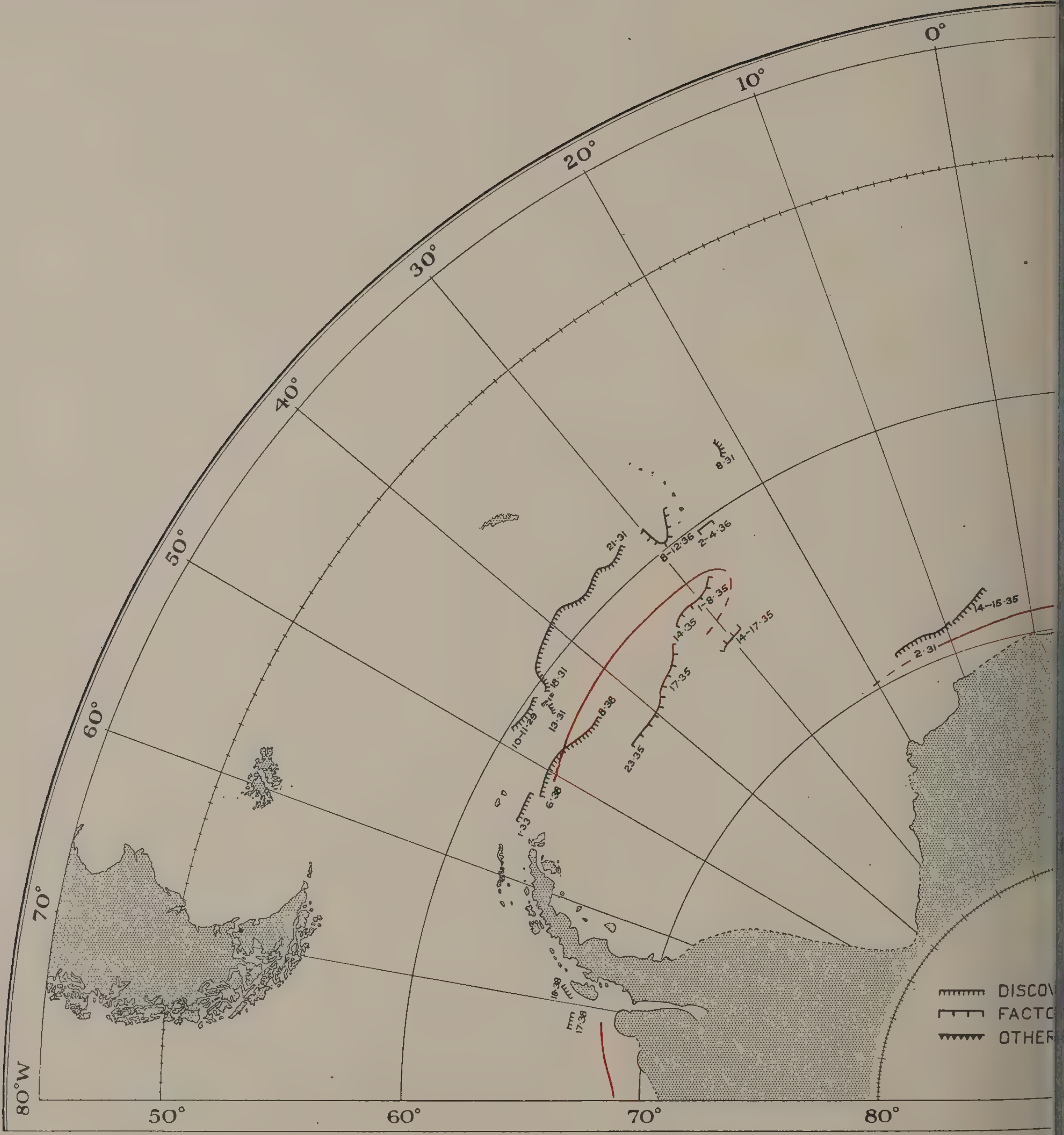
60°
50°
TEE'S SHIPS
NS
7·31
4·31
5·31
29·30
14·34
1·31
8–9·31
9·31
10·31
2·34
10·16
24·38
12·30
11·31
31·33
17·38
15·38
16·38
27·32
26·35
22·35
16–19·35
5·38
26–31·36
2·35
29–31·34
24·31
25–26·31
12·31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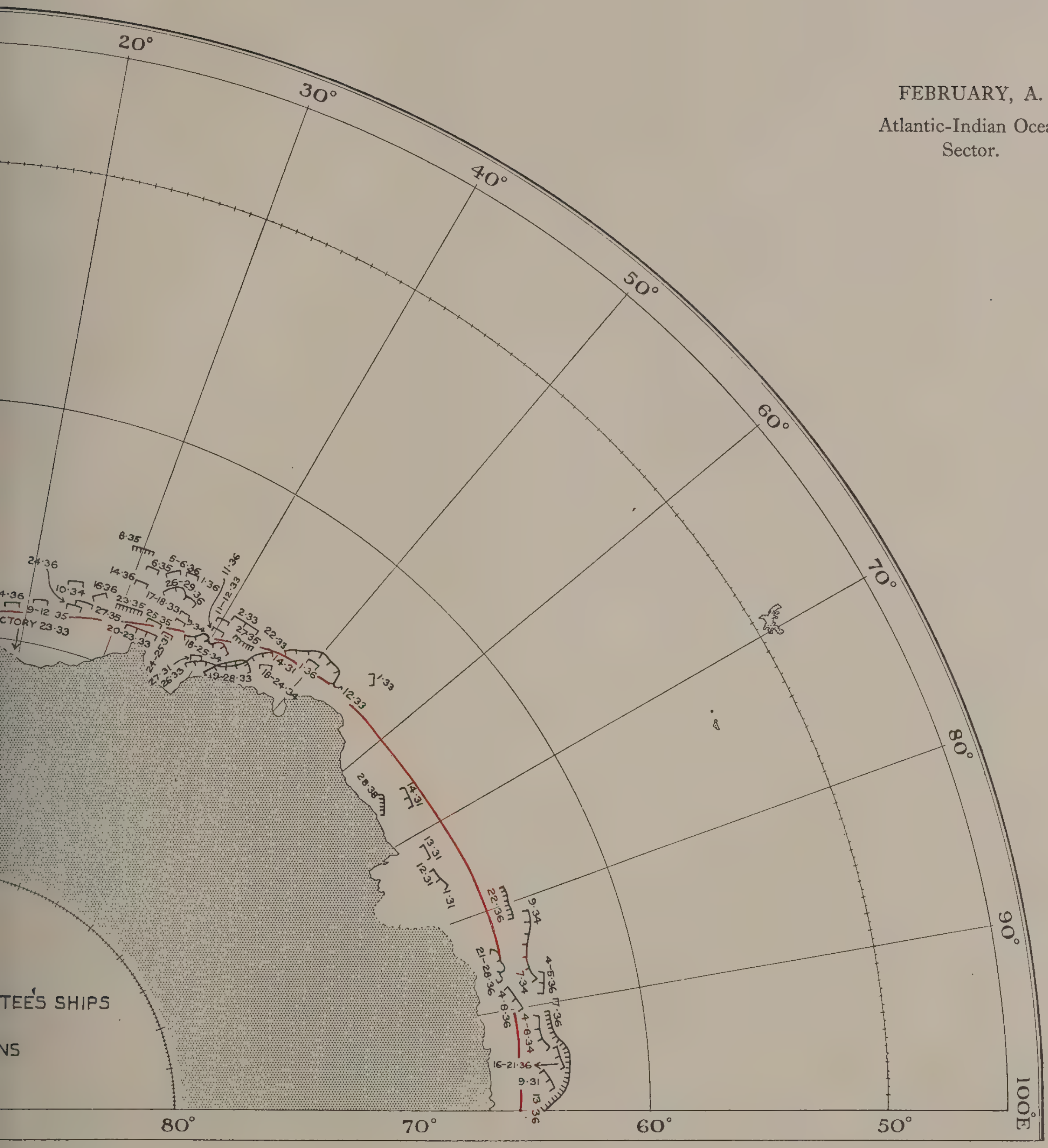
60°
70°
80°W
50°
60°
70°
80°
8·31
21·31
8–12·36
2–4·36
1–8·35
14·35
14–17·35
17·35
18·31
13·31
10–11·29
8·36
23·35
6·36
1·33
14–15·35
2·31
18·38
17·38
DISCOV
FACT
OTHER

PLATE LXXXVI

FEBRUARY, A.

Atlantic-Indian Ocean
Sector.


20°
30°
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80°
90°
100°E
80°
70°
60°
50°
8·35
24·36
5-6·36
6·35
11·36
14·36
26-29·36
1·36
4·36
10·34
16·36
17-18·33
11-12·33
9-12 35
23·35
25 35
27·35
9·34
2·33
CTORY 23·33
20-23·33
27·35
22·33
18-25·34
24-25·31
14·31
27·31
26·33
19-28·33
18-24·34
1·36
1·33
12·33
28·36
14·31
13·31
12·31
1·31
22·36
9·34
21-28·36
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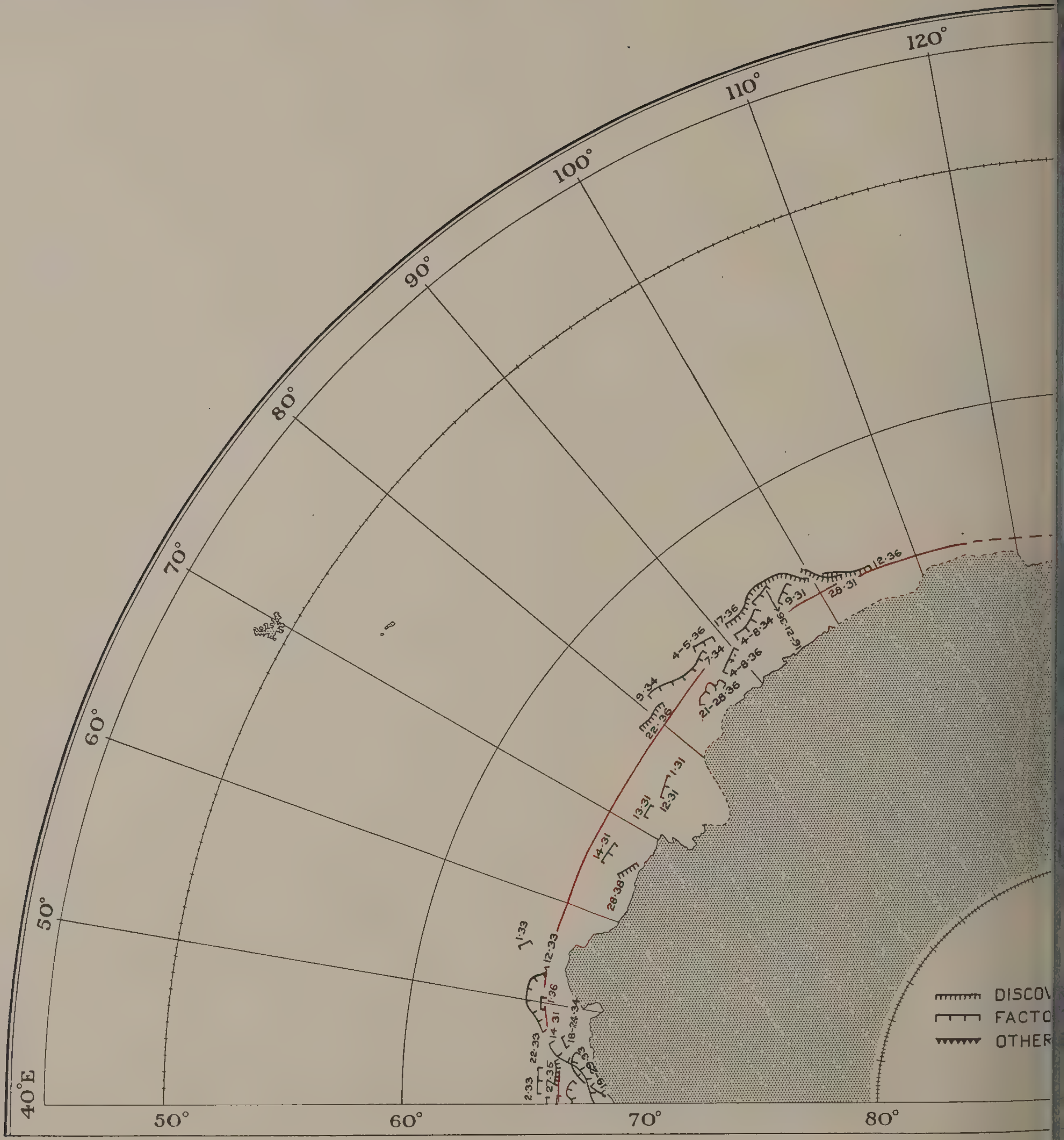
4-5·36
4-8·36
17·36
4-8·34
16-21·36
9·31
13 36
TEES SHIPS
NS


120°
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40°E
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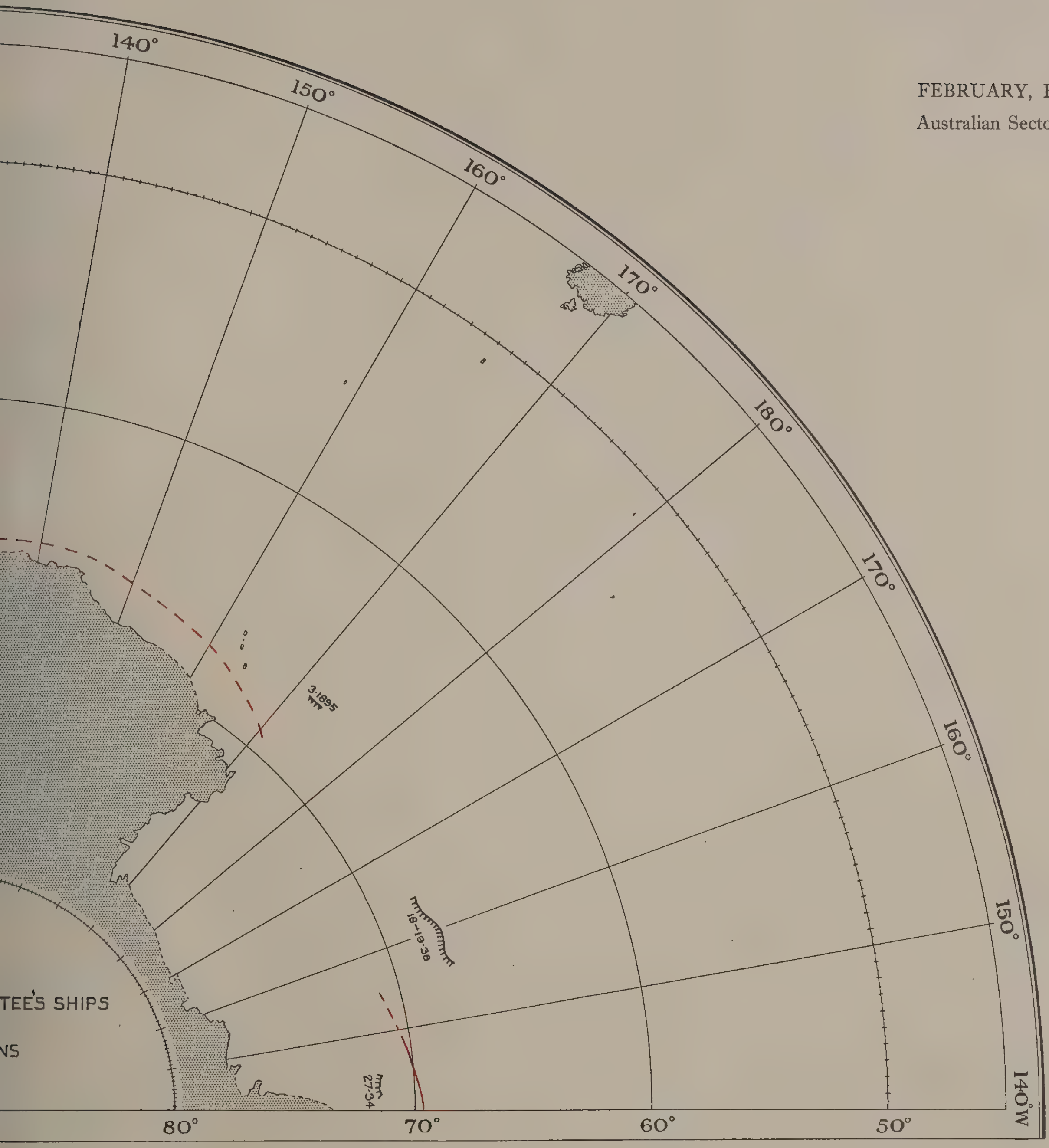
80°
12·36
28·31
9·31
17·36
4–8·34
16–21·36
4–5·36
7·34
4–8·36
9·34
21–28·36
22·36
1·31
12·31
13·31
14·31
28·38
1·33
12·33
1·36
14 31
18–24·34
22·33
27·35
2·33
DISCOV
FACTO
OTHER

PLATE LXXXVII

FEBRUARY, B.
Australian Sector.


140°
150°
160°
170°
180°
170°
160°
150°
140°W
80°
70°
60°
50°
3·1895
18–19·38
27·34
TEE'S SHIPS
NS

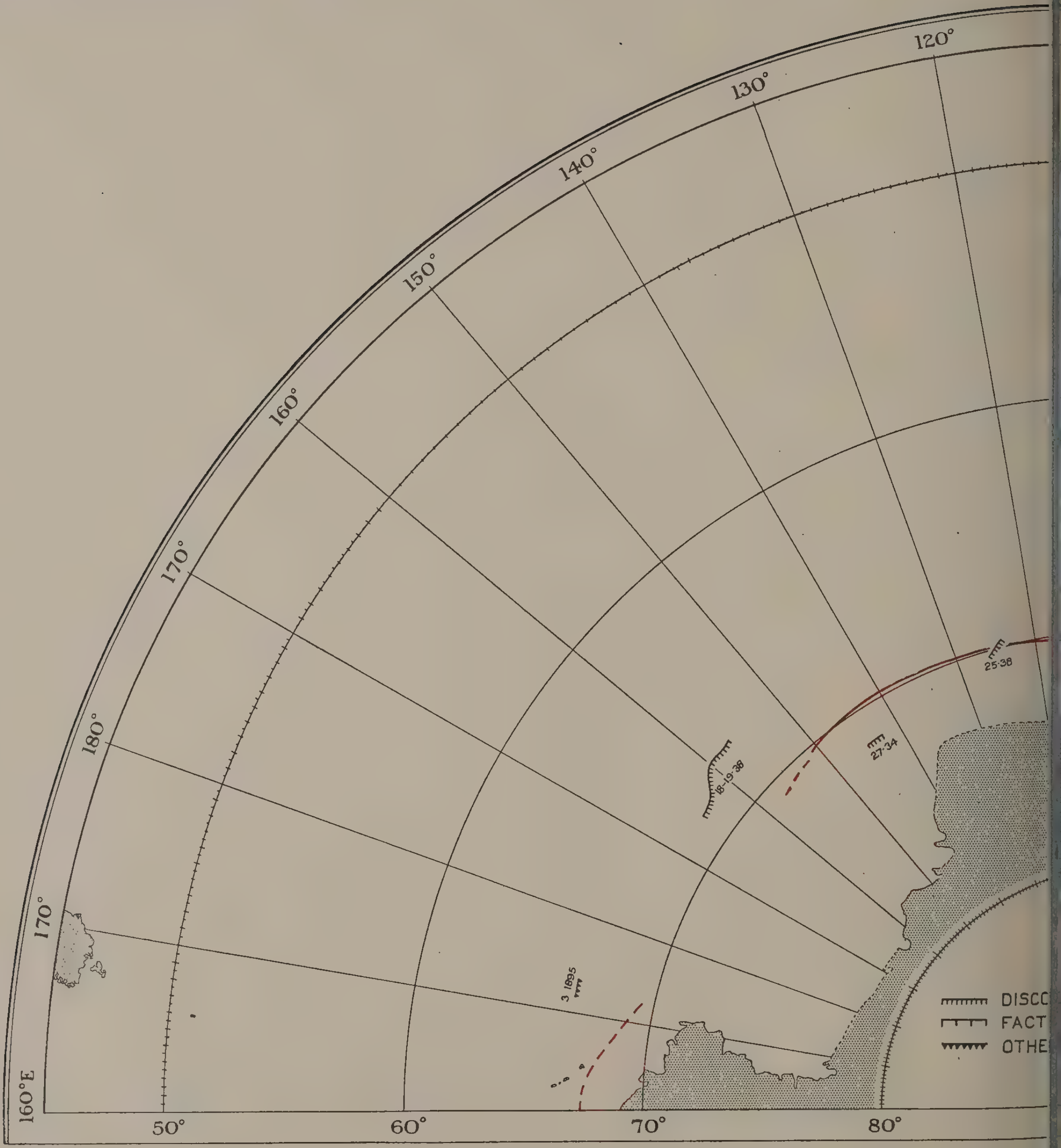
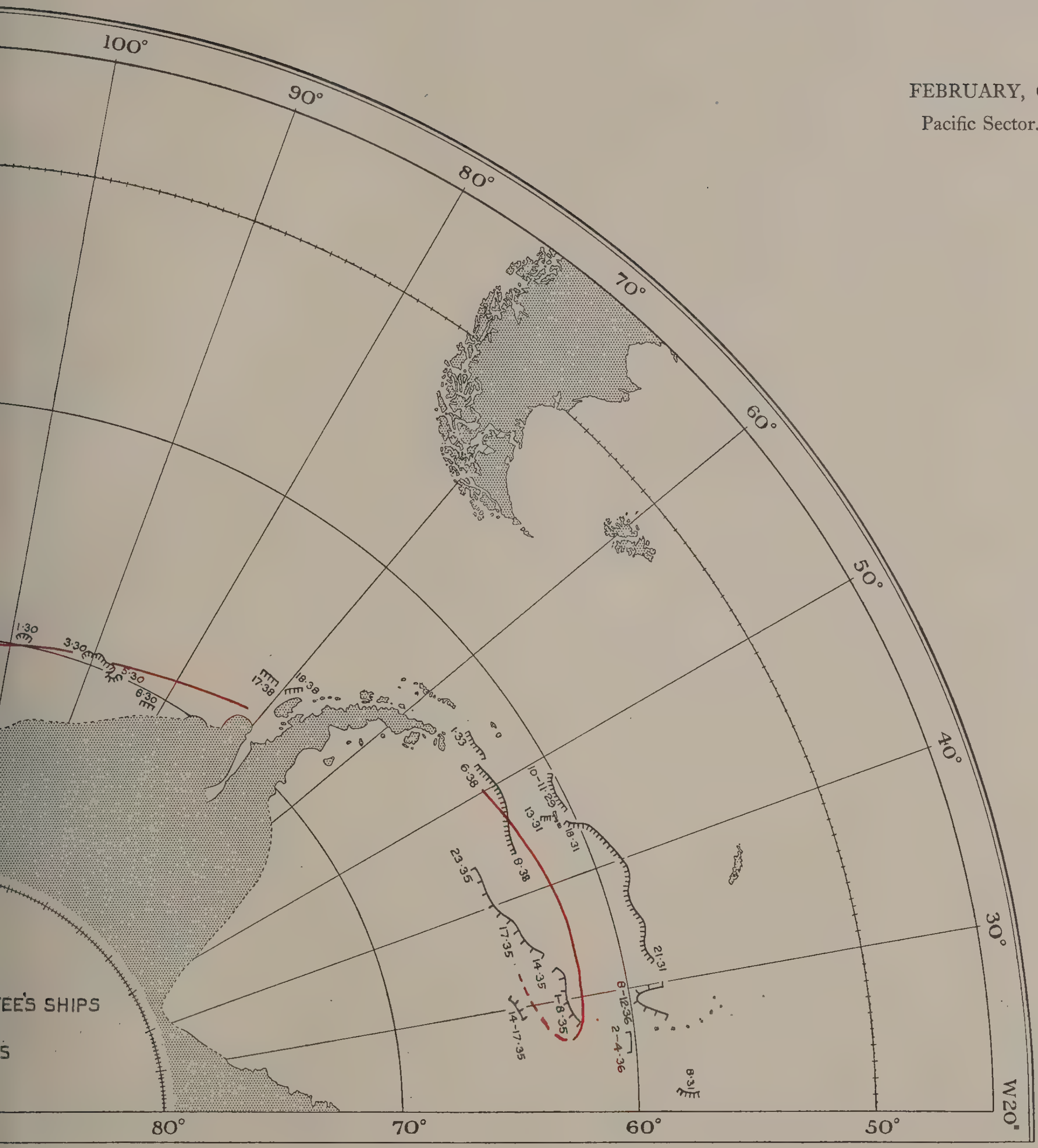

120°
130°
140°
150°
160°
170°
180°
170°
160°E
50°
60°
70°
80°
25·38
27·34
18-19·38
3 1895
DISC
FACT
OTHE

PLATE LXXXVIII

FEBRUARY, C.

Pacific Sector.


100°
90°
80°
70°
60°
50°
40°
30°
W20°
80°
70°
60°
50°
1·30
3·30
5·30
6·30
17·38
18·38
1·33
6·38
10–11·29
13·31
18·31
8·38
23·35
17·35
14·35
8·35
14–17·35
8–12·36
2–4·36
21·31
8·31
EE'S SHIPS
S

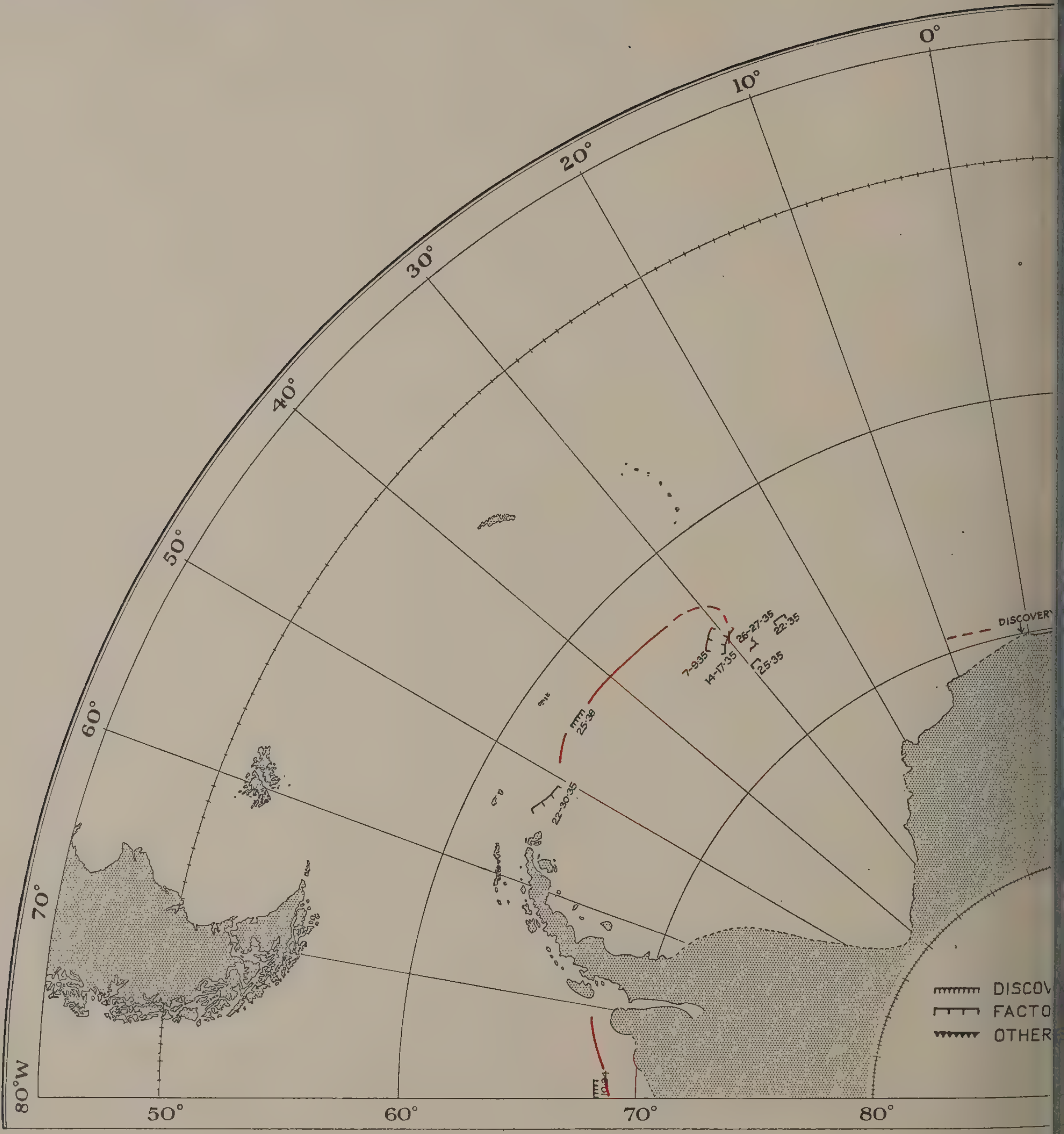
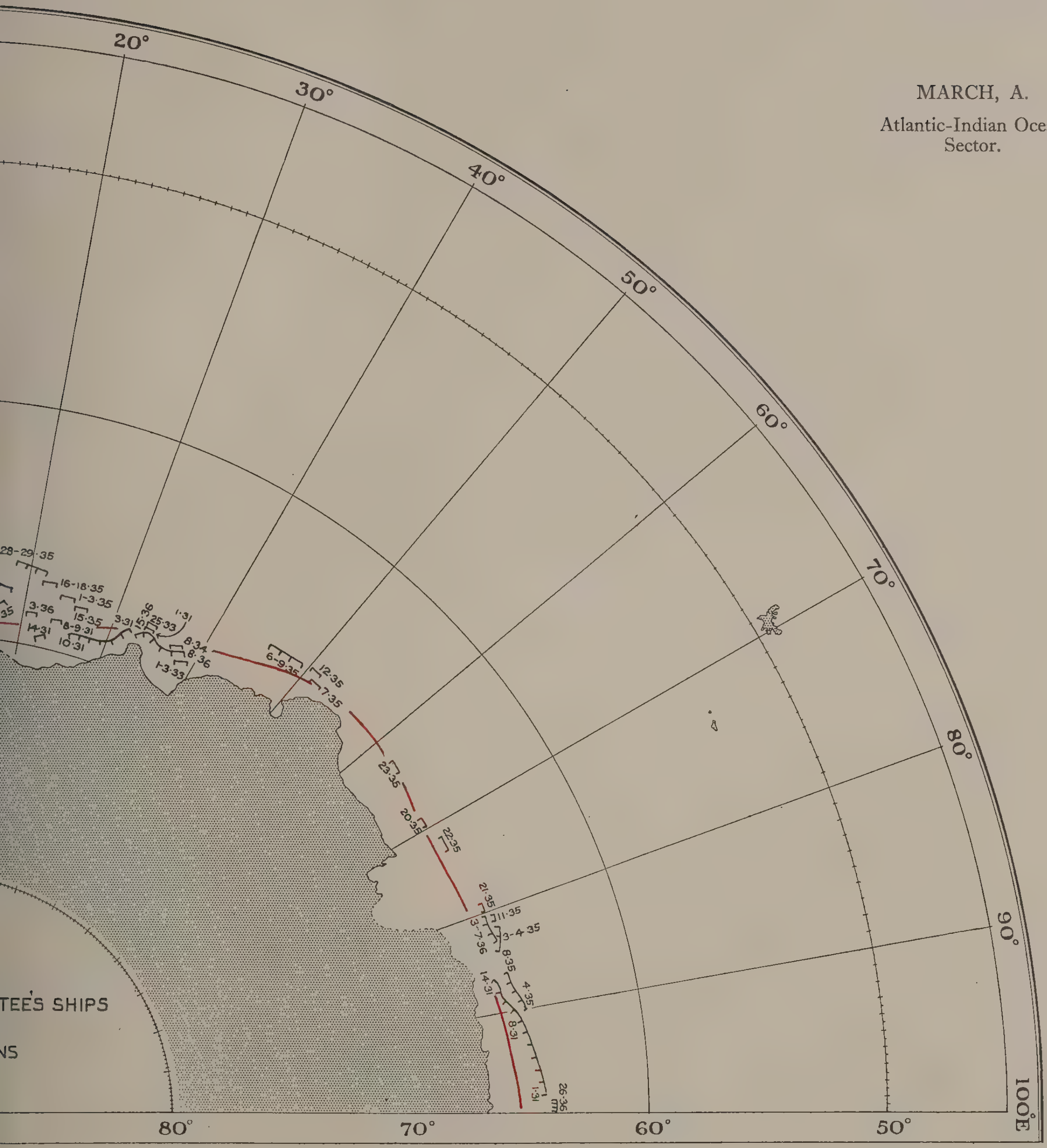

0°
10°
20°
30°
40°
50°
60°
70°
80°W
50°
60°
70°
80°
DISCOVERY
7-9·35
14-17·35
26-27·35
22·35
25·35
25·38
22-30·35
10·34
DISCOV
FACTO
OTHER

PLATE LXXXIX

MARCH, A.

Atlantic-Indian Ocean
Sector.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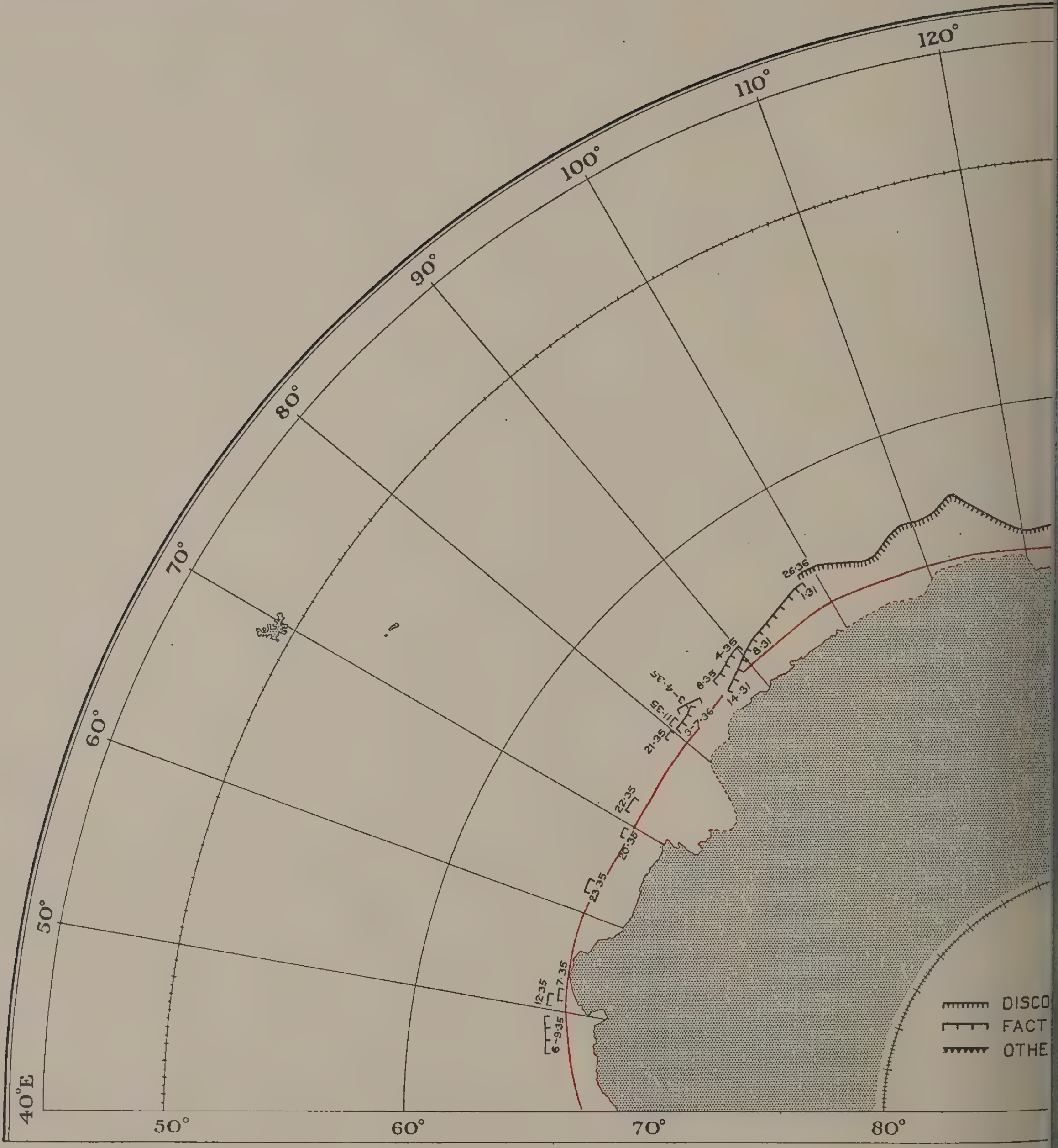
30°
40°
50°
60°
70°
80°
90°
100°E
80°
70°
60°
50°
28-29·35
16-18·35
1-3·35
35
3·36
15·35
8-9·31
14·31
10·31
3·31
15·36
25·33
1·31
8·34
8·36
1-3·33
6-9·35
12·35
7·35
23·35
20·35
22·35
21·35
11·35
3-7·36
3-4·35
8·35
14·31
4·35
8·31
1·31
26·36
TEES SHIPS
NS


120°
110°
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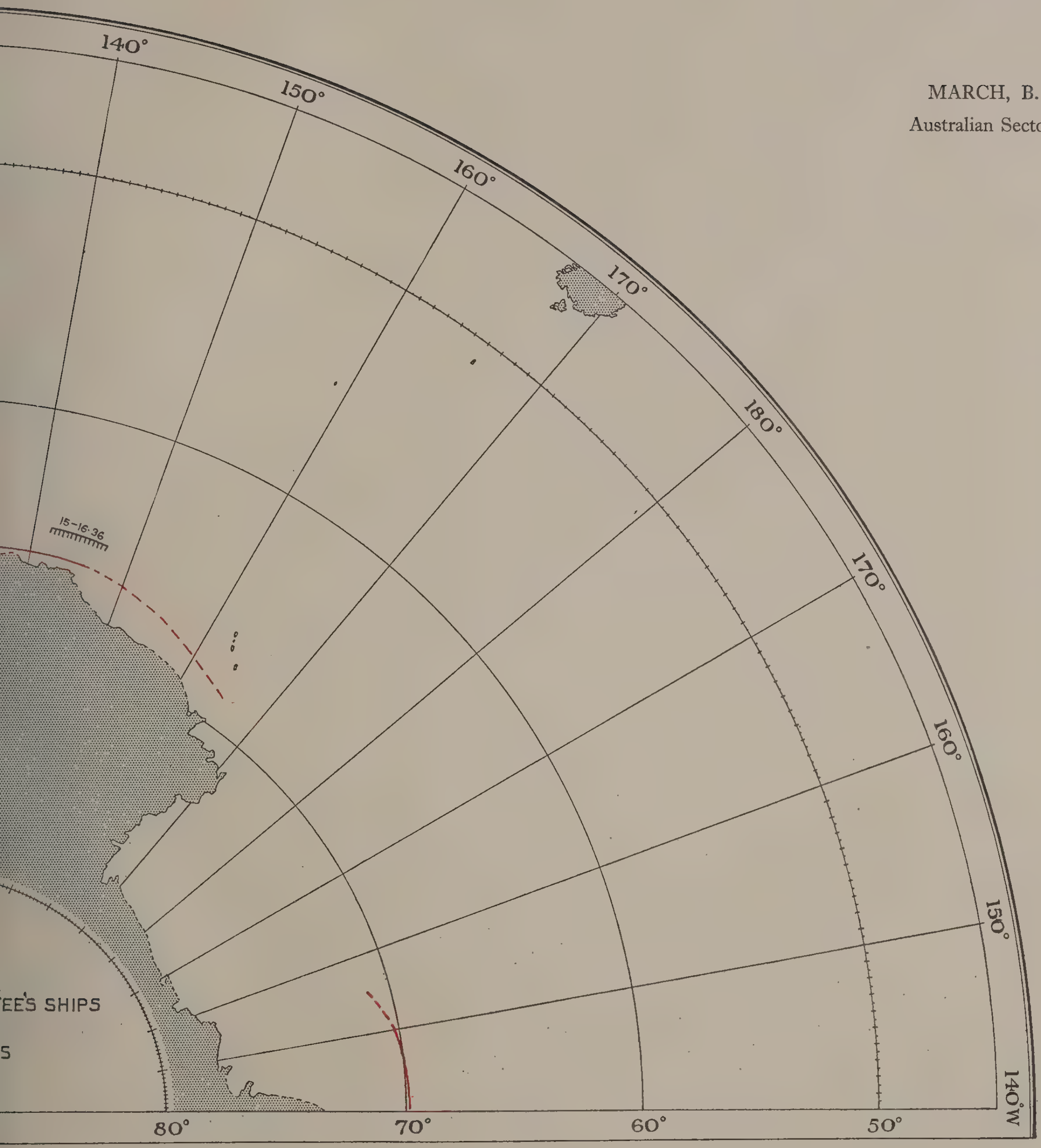
50°
40°E
50°
60°
70°
80°
26·36
1·31
4·35
8·31
8·35
3-4·35
11·35
3-7·36
14·31
21·35
22·35
20·35
23·35
12·35
7·35
6-9·35
DISCO
FACT
OTHE

PLATE XC

MARCH, B.
Australian Sector.


140°
150°
160°
170°
180°
170°
160°
150°
140°W
15-16·36
EES SHIPS
S
80°
70°
60°
50°

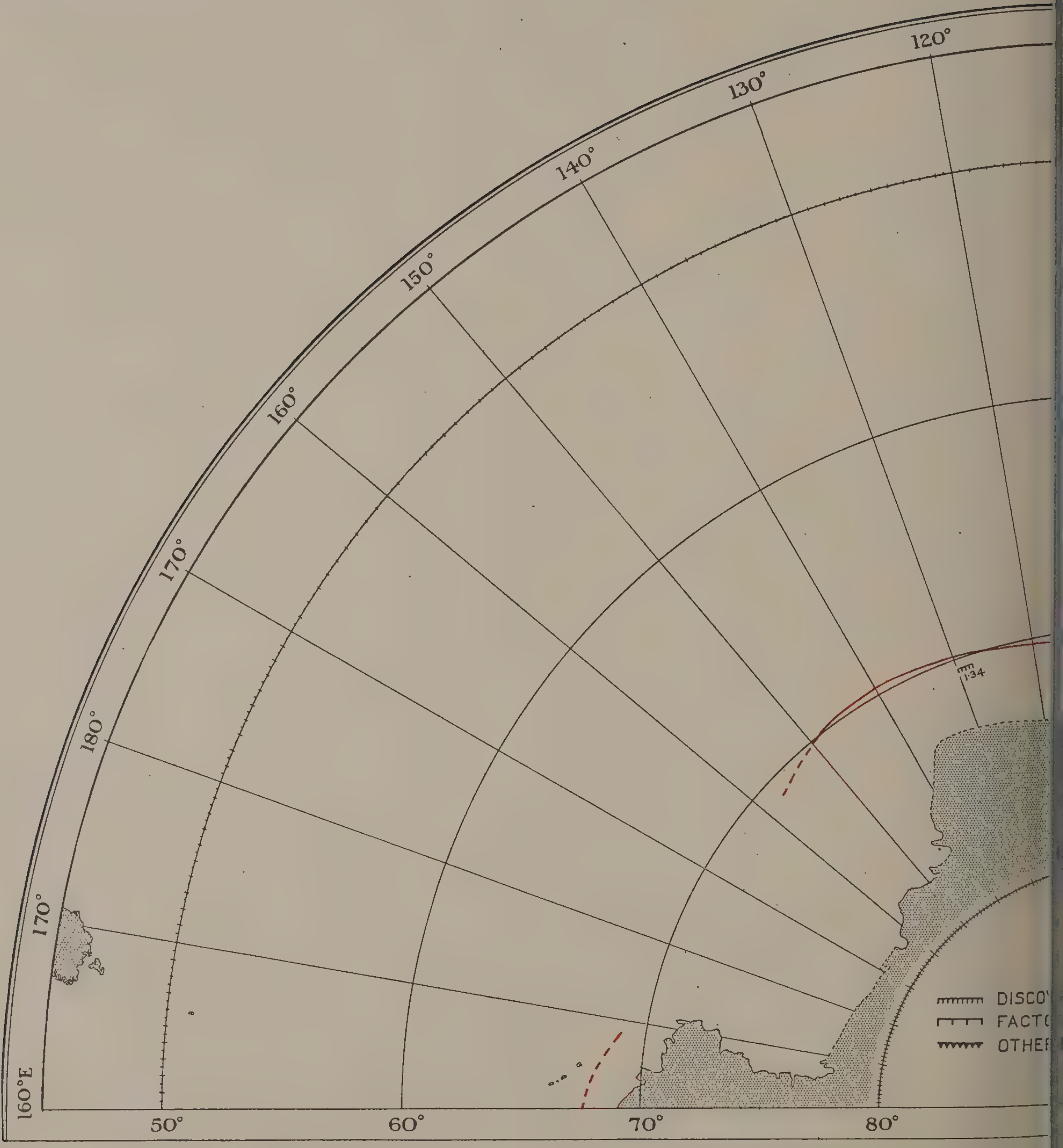
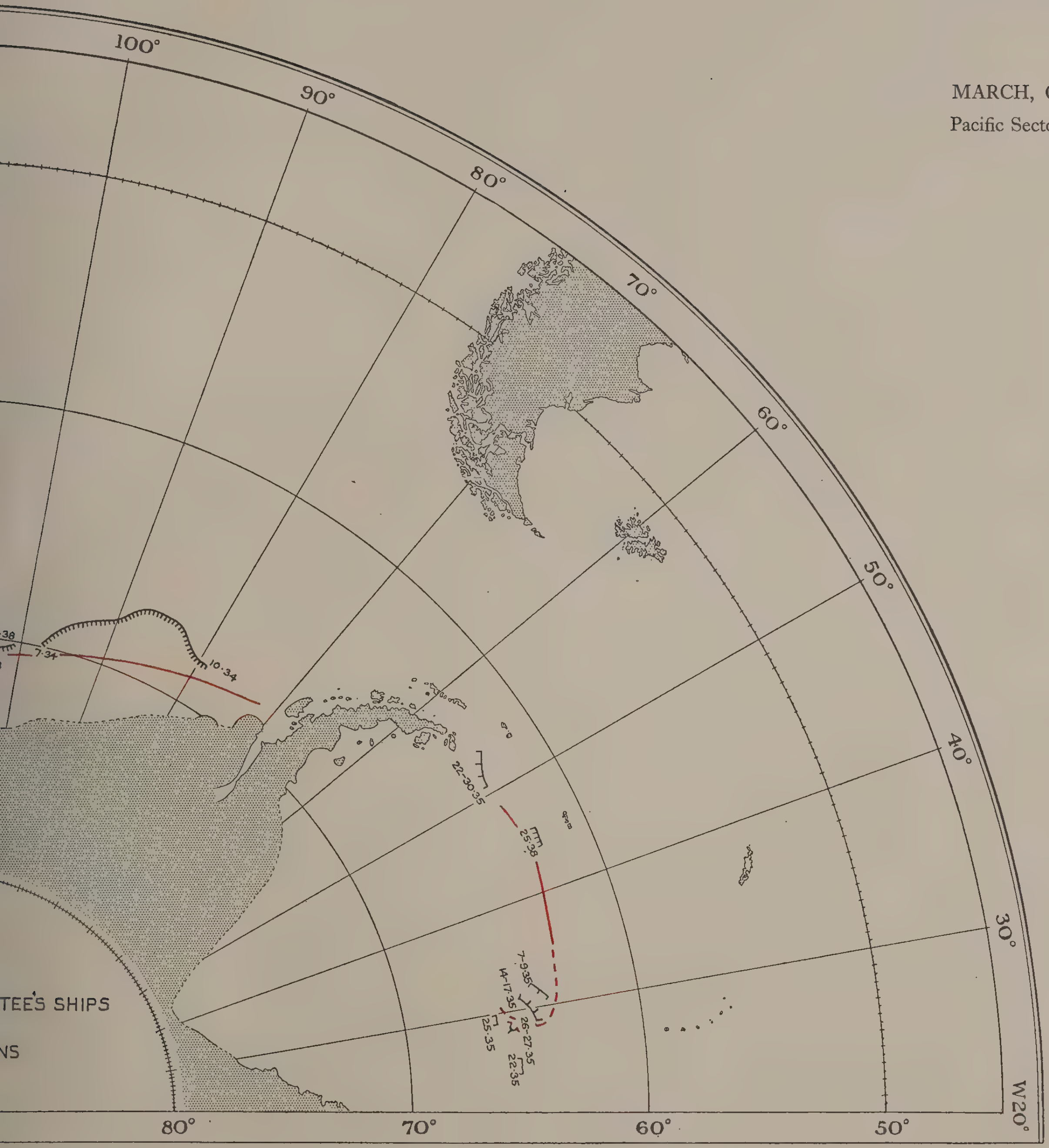

120°
130°
140°
150°
160°
170°
180°
170°
160°E
50°
60°
70°
80°
1·34
DISCO
FACT
OTHE

PLATE XCI

MARCH, C.
Pacific Sector.


100°
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30°
W20°
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60°
50°
·38
7·34
10·34
22-30·35
25·38
7-9·35
14-17·35
26-27·35
25·35
22·35
TEE'S SHIPS
NS

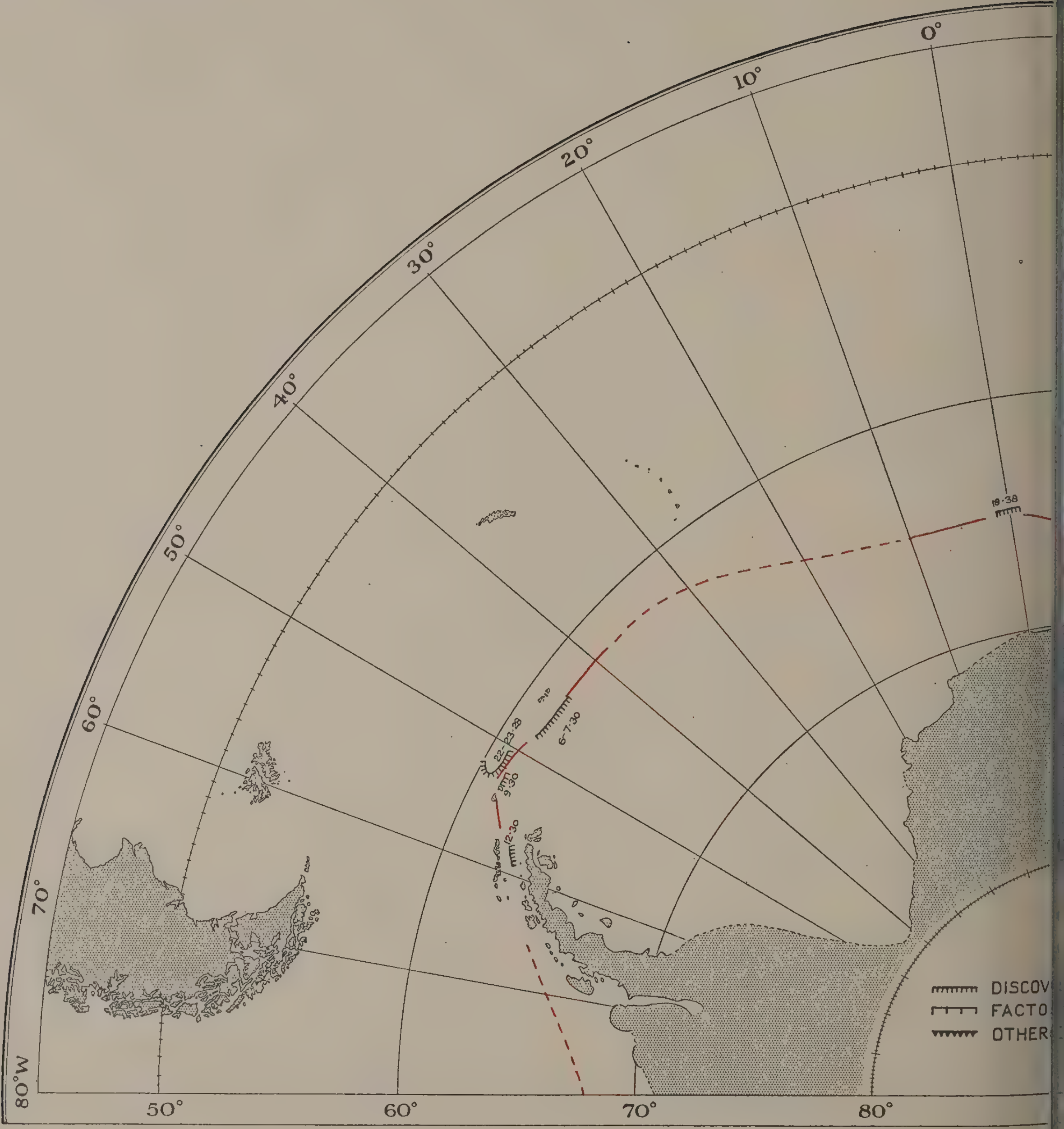
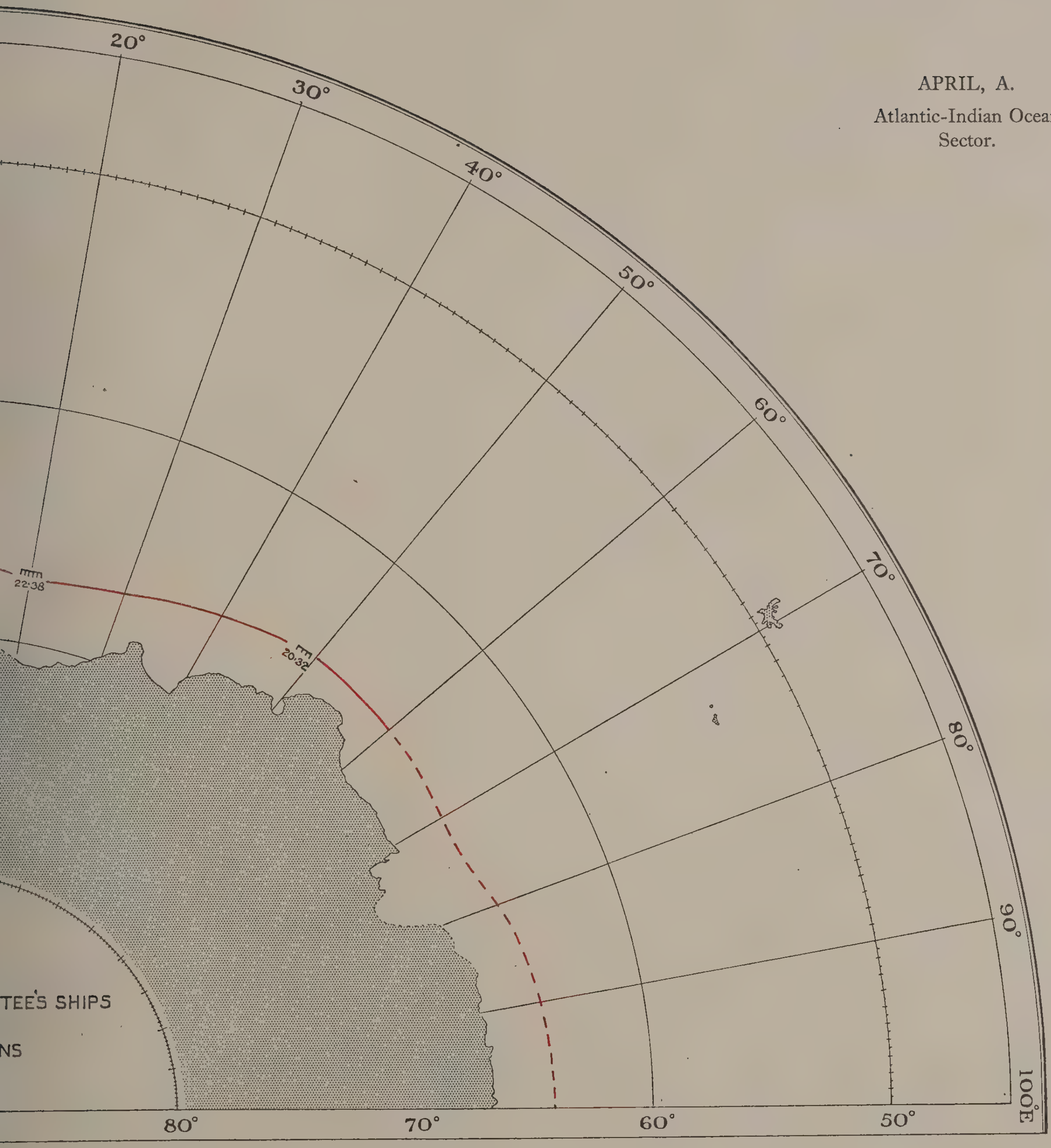

0°
10°
20°
30°
40°
50°
60°
70°
80°W
50°
60°
70°
80°
19·38
9·10
6-7·30
22-23·28
9·30
12·30
DISCOV
FACTO
OTHER

PLATE XCII

APRIL, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
22·38
20·32
TEE'S SHIPS
NS
80°
70°
60°
50°

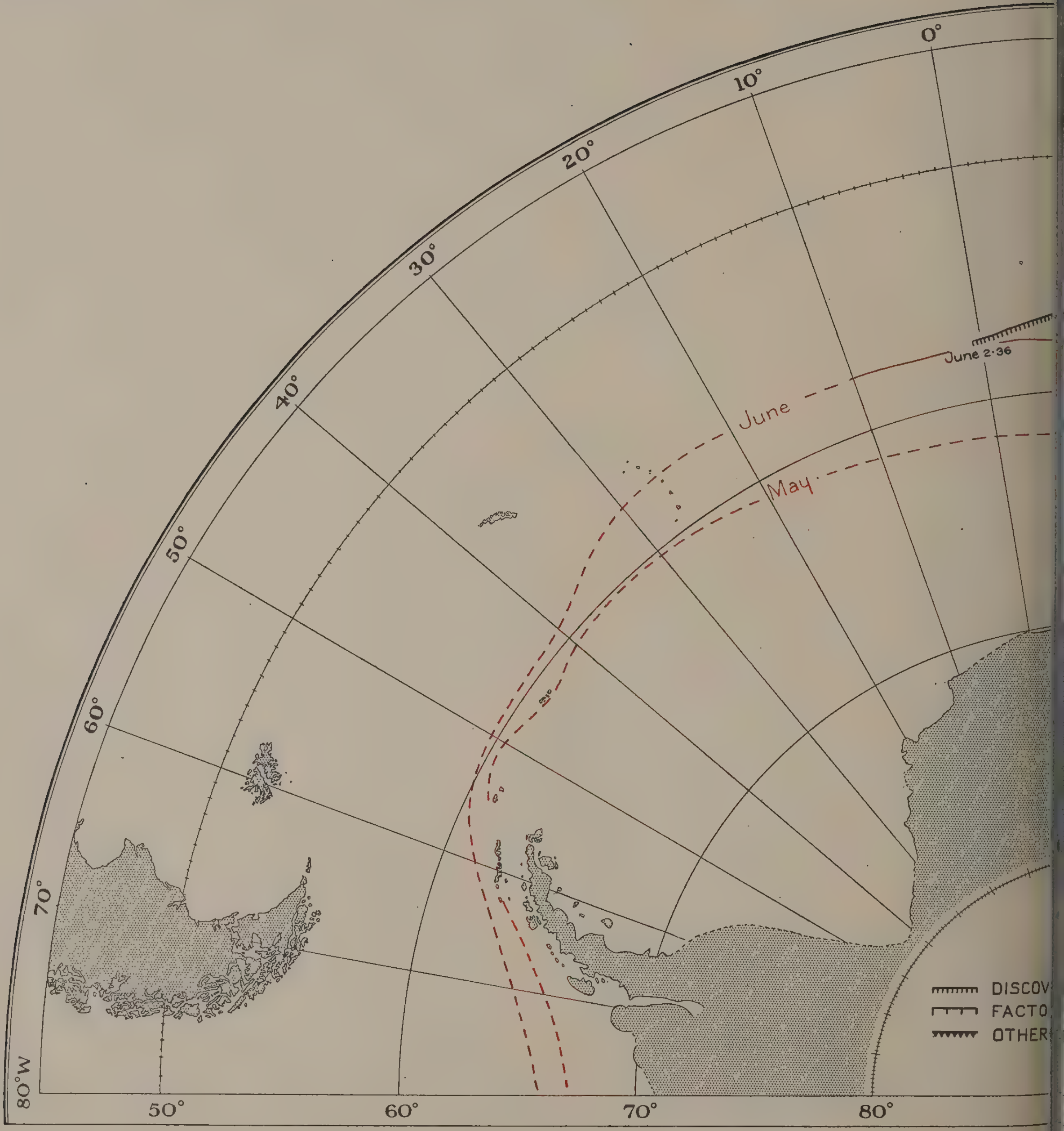
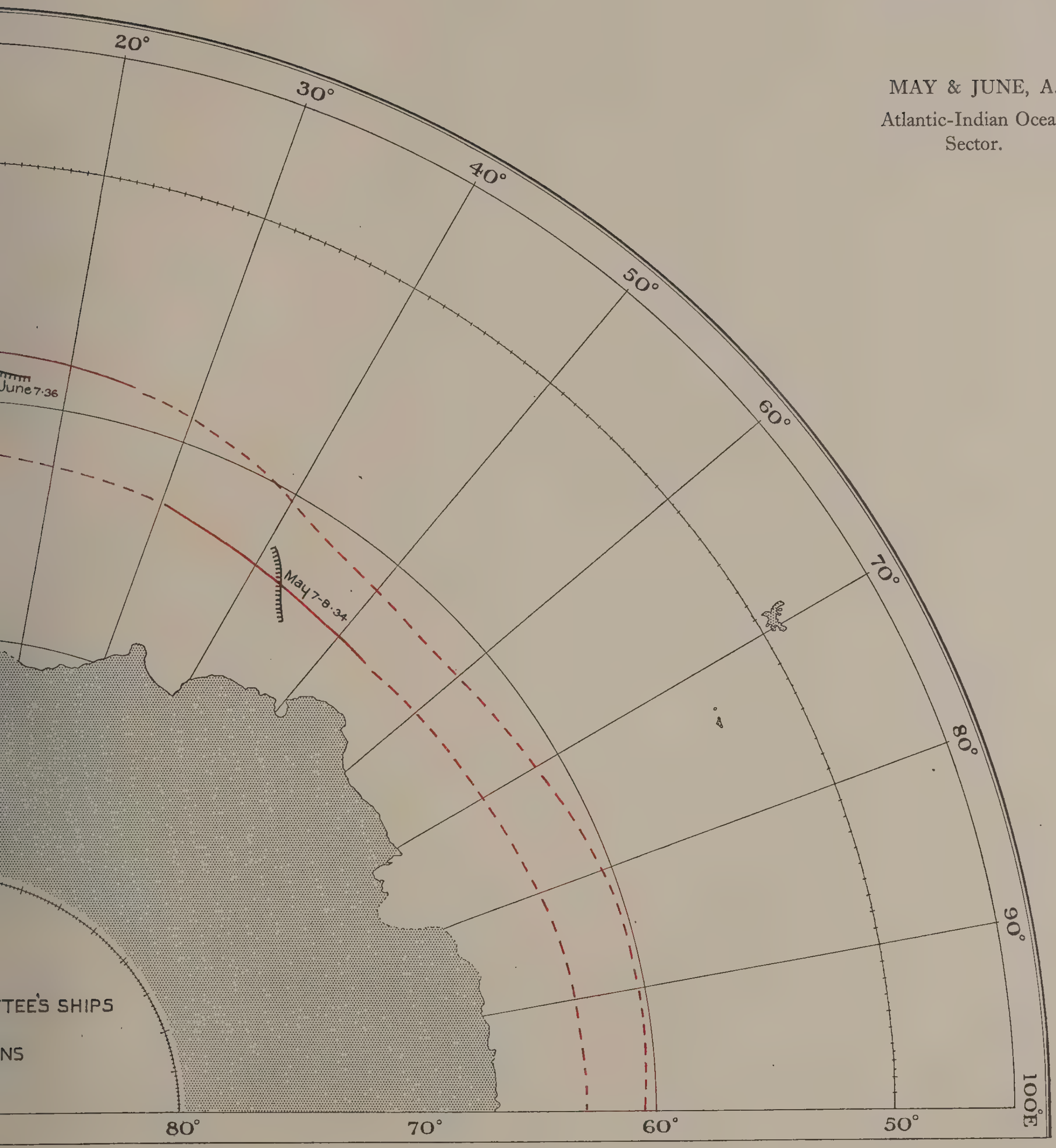

0°
10°
20°
30°
40°
50°
60°
70°
80°W
50°
60°
70°
80°
June 2·36
June
May
DISCOV
FACTO
OTHER

PLATE XCIII

MAY & JUNE, A.

Atlantic-Indian Ocean
Sector.


20°
30°
40°
50°
60°
70°
80°
90°
100°E
June 7·36
May 7-8·34
TEE'S SHIPS
NS
80°
70°
60°
50°

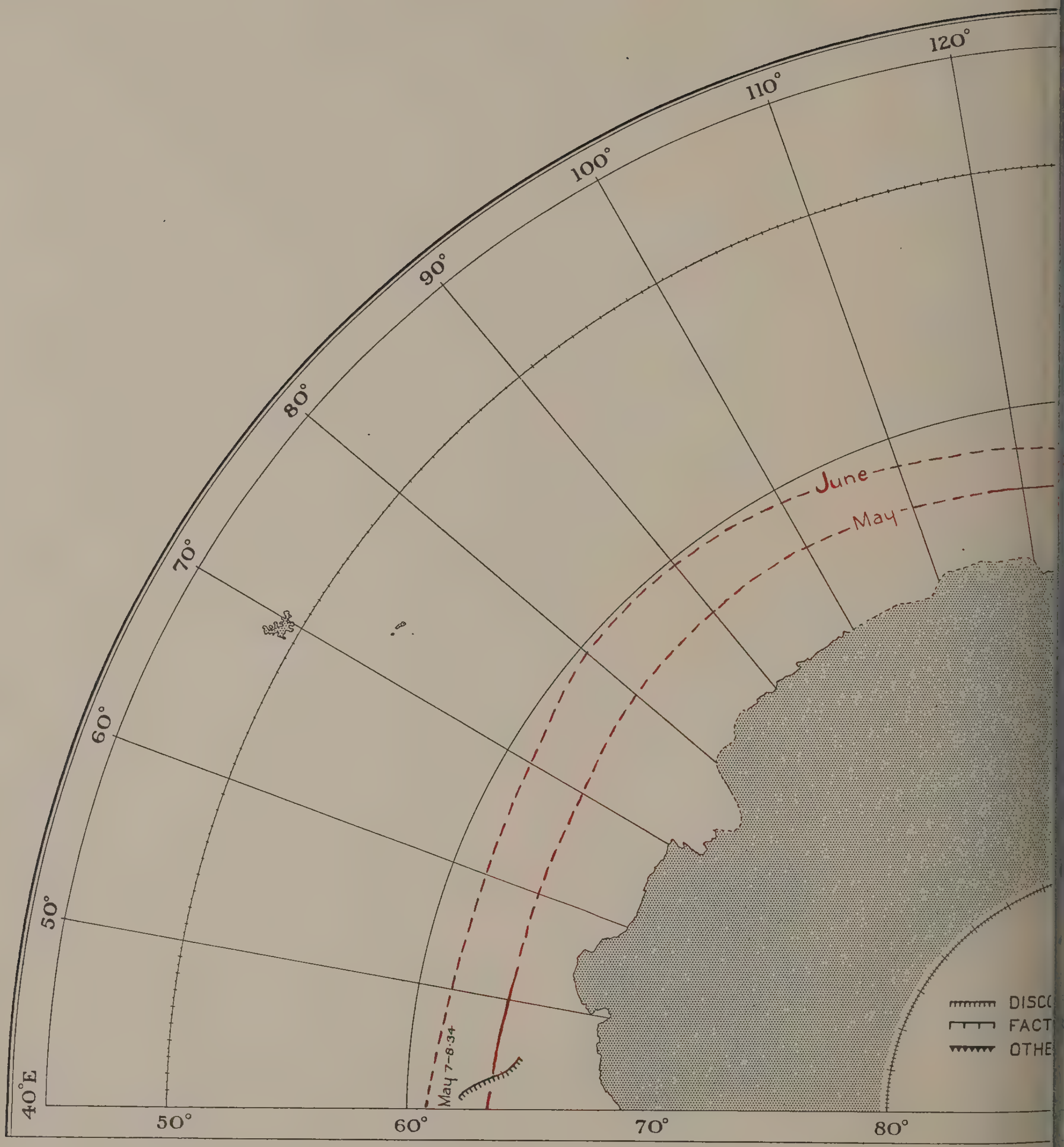
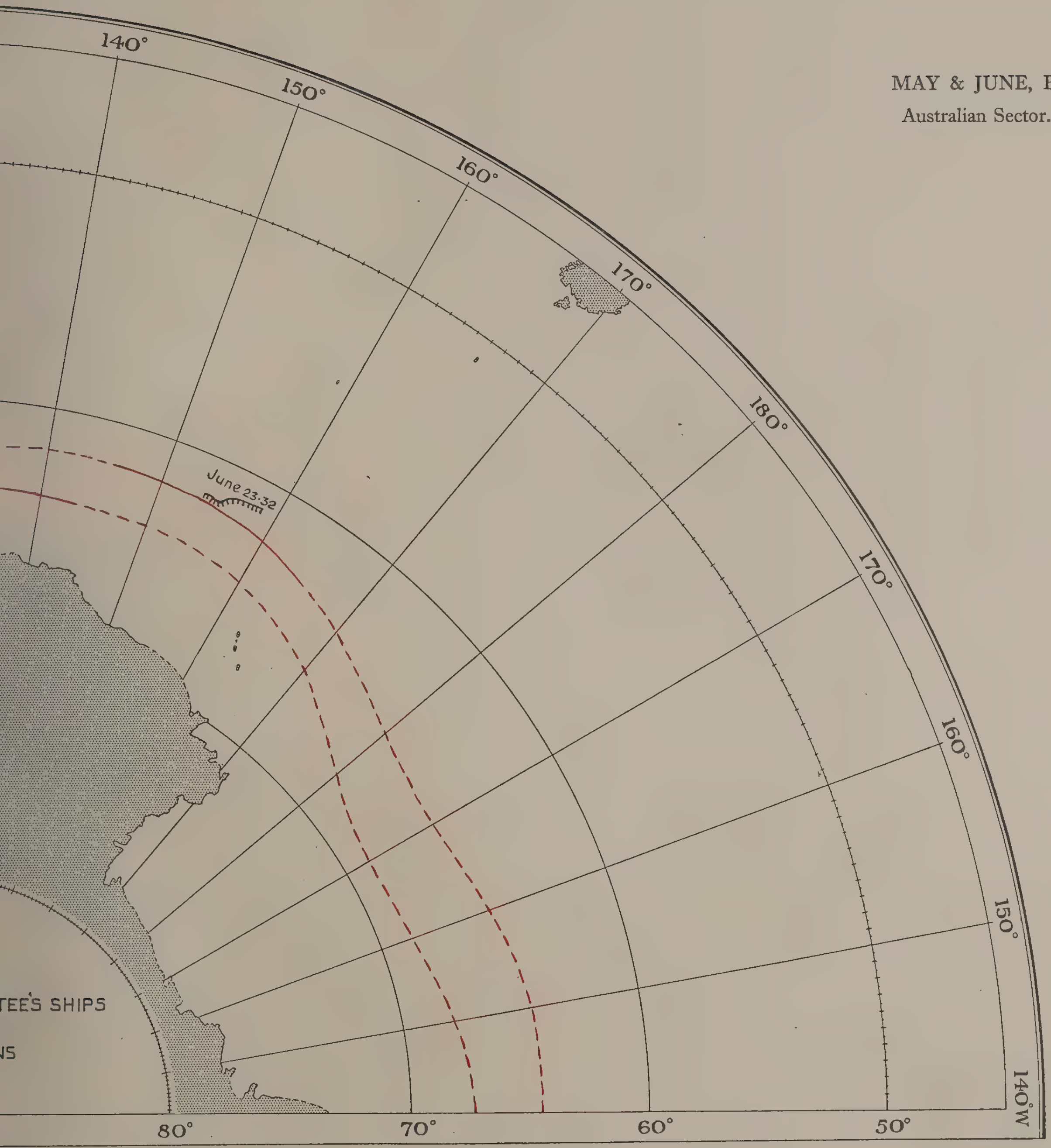

120°
110°
100°
90°
80°
70°
60°
50°
40°E
50°
60°
70°
80°
June
May
May 7-8-34
DISC
FACT
OTHE

PLATE XCIV

MAY & JUNE, B.
Australian Sector.


140°
150°
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150°
140°W
June 23·32
TEE'S SHIPS
NS
80°
70°
60°
50°

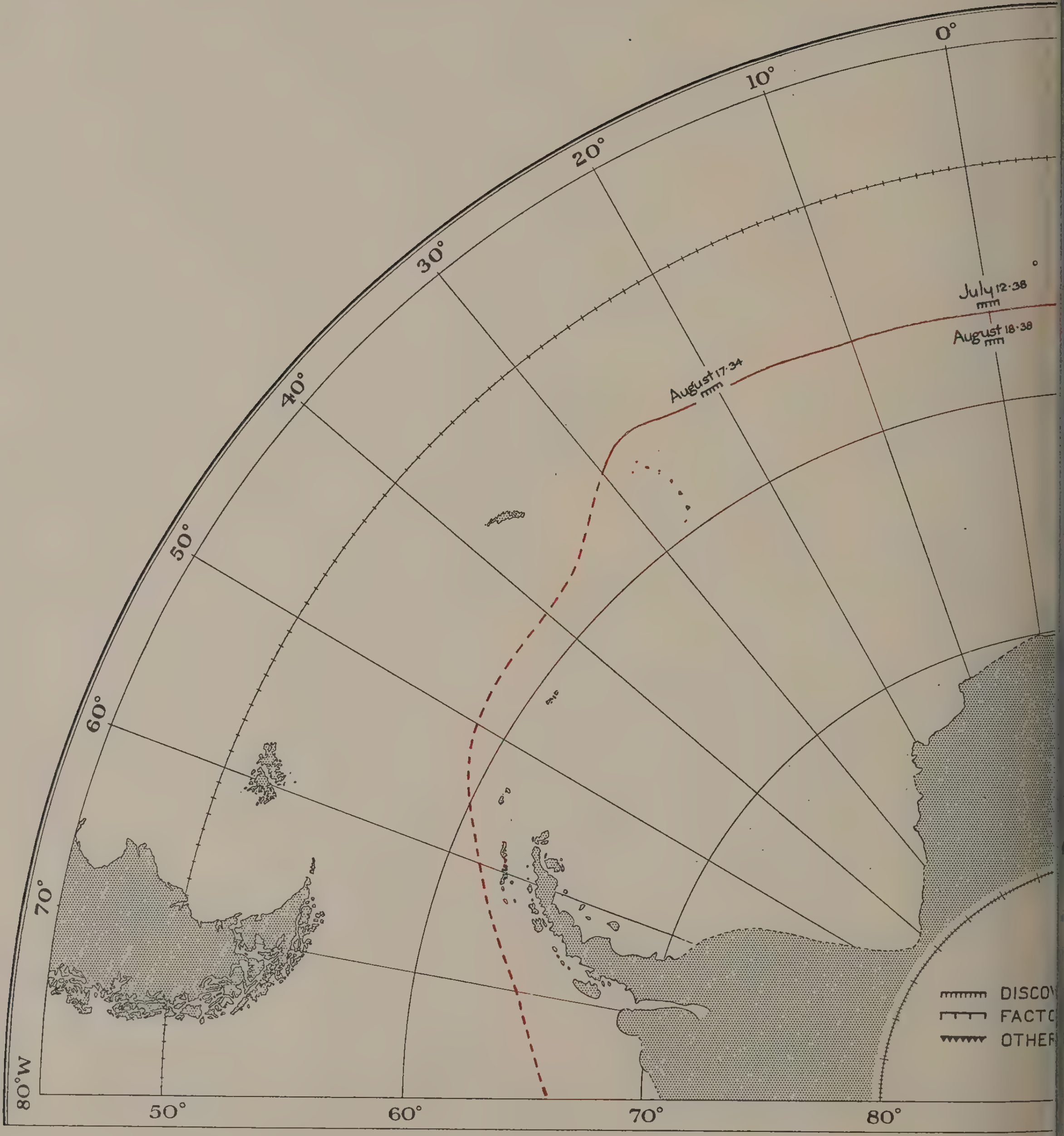
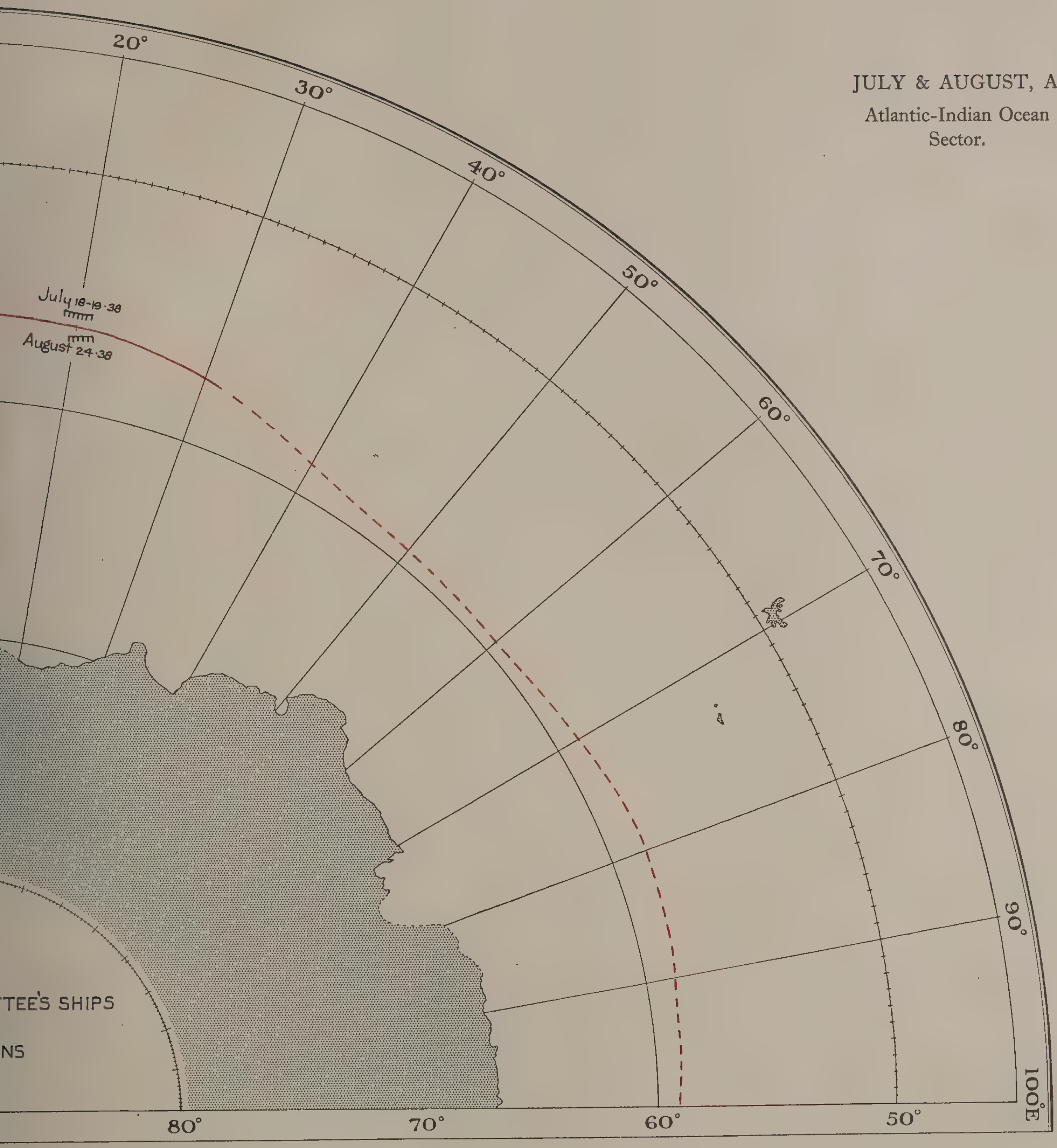

0°
10°
20°
30°
40°
50°
60°
70°
80°W
July 12·38
August 18·38
August 17·34
DISCOV
FACTO
OTHER
50°
60°
70°
80°

PLATE XCV

JULY & AUGUST, A.
Atlantic-Indian Ocean
Sector.


20°
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July 18-19.38
August 24.38
TEE'S SHIPS
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